JPRS-USB-85-004

12 August 1985

USSR Report

SPACE BIOLOGY AND AEROSPACE MEDICINE

SPACE BIOLOGY AND AEROSPACE MEDICINE

Vol 19, No 2, March-April 1985

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Translation of the Russian-language bimonthly journal KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA published in Moscow by Izdatel'stvo "Meditsina"

CONTENTS

PUBLICATION DATA

English title	:	SPACE BIOLOGY AND AEROSPACE MEDICINE, Vol 19, No 2, Mar-Apr 85
Russian title	:	KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA
Editor	:	O. G. Gazenko
Publishing house	:	Meditsina
Place of publication	:	Moscow
Date of publication	:	March-April 1985
Signed to press	:	7 February 1985
Copies	:	1460

SURVEYS

UDC: 629.78:612.014.477-064

LABYRINTHINE AND EXTRALABYRINTHINE MECHANISMS OF DEVELOPMENT OF MOTION SICKNESS IN WEIGHTLESSNESS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 10 Oct 83) pp 4-11

[Article by A. D. Yegorov and Ye. M. Yuganov]

[English abstract from source] This paper describes an important problem of aerospace medicine, i.e. space motion sickness. The review surveys relevant Soviet and foreign publications. On their basis, including their own data, the authors discuss possible mechanisms of the symptom-complex in the weightless state. The authors put forth their own ideas concerning current hypotheses of space motion sickness and discuss potential applicability of the theoretical concepts with respect to the prevention of this adverse symptom-complex. The authors describe selected outlines in the study of mechanisms of space motion sickness and in the development of specific countermeasures.

[Text] Analysis of spaceflight observations revealed that, in about 40-50% of the cases, there is development of varying degrees of symptoms of inflight motion sickness (MS) ranging from drowsiness, apathy and unpleasant sensations in the epigastric region to nausea and vomiting (Table 1).

According to the cited data, the fewest cases of MS occurred during flights aboard 1-2-seat small spacecraft. It should be noted that, according to the data of Graybiel et al. [27], 9 out of the 25 cosmonauts of the Apollo command module developed MS in flight. At the same time, only 3 out of the 12 pilots of the lunar module reported mild symptoms (heaviness in the gastric regions or loss of appetite) on the flight trajectory to the moon. No symptoms of MS were observed while on the surface of the moon or on the flight trajectory toward earth [27, 33].

Two types of effects are distinguished during spaceflights that are related to functional impairment of the vestibular system [27]:

> Reflex motor reaction arising immediately after insertion in orbit, in the form of postural illusions, feeling of rotation, nystagmus and vertigo.

Gradually developing space MS. In this regard, it should be noted that, according to L. N. Kornilova [11], 80% of the 36 cosmonauts who participated in the Salyut-6 and Salyut-7--Soyuz programs developed sensory manifestations of MS in flight and 50%, autonomic ones.

Table 1. Incidence of MS* during spaceflights [11, 33]

Manned flights					
in USSR (through 1982)			in United States		
program	number of cosmonauts	missions	program	number of astronauts	missions
Vostok	6	2	Mercury	6	0
Voskhod	5	3	Gemini	20	0
Soyuz**	24	11	Apollo	33	11
Salyut-4	4	2	Apollo-Soyuz	3	0
Salyut-6, Salyut-7--Soyuz complex	36	18	Shuttle	12	5

*We included as MS cases when one or several typical symptoms appeared, regardless of their severity.

**This line includes cosmonauts who made independent flights on Soyuz series spacecraft.

The most typical complaints with development of space MS were different symptoms of MS or combinations in the form of salivation, regurgitation, discomfort in the epigastric region, nausea and vomiting. In some cases there was also pallor of the integument and cold sweat, development of apathy, sluggishness, drowsiness, fatigue, weakness, impaired spatial orientation, loss of appetite, etc. As a rule the general condition improved after vomiting. These symptoms could be provoked or enhanced by motor activity and optokinetic stimuli (observations through windows).

Pallor of the integument, cold sweat, nausea and vomiting are the most important symptoms of MS, including its space form. These MS symptoms are manifested in about the same way in the space and ground forms. However, as indicated by Homick and Miller [29], in spaceflight there are cases of sudden vomiting without prior integumental pallor or nausea.

The most marked symptoms of MS are observed in the first days of a flight. No recurrence of MS has been recorded in the course of the same flight. However, there was recurrence of illusions during long-term spaceflights [33].

L. N. Kornilova et al. [11] distinguish three types of adaptation of sensory systems to spaceflight conditions:

Resistant--no autonomic or sensory discomfort, or else mild illusion reactions (52%).

Intensive--marked reaction lasting 2-3 days (36%).

Torpid (protracted)--frequently marked symptoms of vegeto-vestibular discomfort and sensory disturbances (12%) lasting up to 2 weeks. However, we observed a protracted type of reaction with very marked vestibular disturbances.

In subsequent missions, the cosmonauts reported easier and faster adaptation, and less marked MS symptoms than in the first flight. In some cases, MS symptoms appeared following long-term flights in cosmonauts who had presented them in flight.

It should be noted that use of numerous tests to predict the possibility of MS during spaceflights is still insufficiently effective. Apparently this is attributable to the fact that the tests used are aimed at evaluating sensitivity of primarily the vestibular system, with no tests whatsoever to predict individual adaptability to weightlessness.

Mechanisms of Development of Space MS

Change in vestibular system function. Under ordinary living conditions on earth, the vestibular system informs the central nervous system about the direction and magnitude of gravity and inertial forces acting on the body, which provides for maintenance of equilibrium and spatial orientation of the body.

In weightlessness, there is change in vestibular function and its interaction with other sensory systems.

At the present time there are two opposing hypotheses concerning change in receptor function of the vestibular system in weightlessness. According to one of them, there is functional elimination of the otolith system in weightlessness due to loss of mass of the otolith membrane [9, 16, 19-21, 28].

G. L. Komendantov and V. I. Kopanev [9], K. L. Khilov [21] believe that there is deafferentation of the otolith system in weightlessness, which attenuates its inhibitory effect on the semicircular canals and leads to drastic increase in their excitability. For this reason, head movements become supraliminal stimuli, accumulation of which creates the typical effect of vestibulovegetative disorders.

The hypothesis of functional deafferentation of the labyrinth is inconsistent with experimental data about the efficacy of only a stimulus that is directed tangentially to the macula [35], and for this reason impulsation from utricular otoliths would be the same with any position of the head in weightlessness as with the head in vertical position on the ground.

The other hypothesis, which is being developed primarily in the works of Ye. M. Yuganov [23, 24], views weightlessness as a distinctive minus-stimulus for otolith receptors. This hypothesis is based on experimental data, which revealed that there was heightened sensitivity of the otolith system to linear accelerations and galvanic current during brief (about 30 s)

weightlessness. In addition, there was inhibition of reactions from receptors of the semicircular canals in the form of increased latency period and attenuation of several vestibular reactions during rotation tests and use of galvanic current which, in the author's opinion, was due to increased impulsation from the otolith system during brief weightlessness [26] and more marked influence of otoliths on the semicircular canals. This hypothesis is quite consistent with general physiological conceptions to the effect that staggered reduction of force of a stimulus could lead to brief increase in impulsation from receptors [5, 18]. However, because of the short duration of this effect (several tens of seconds) it cannot be viewed as the cause of space MS.

It should be noted that during long exposure to weightlessness one observes a decline in sensitivity of the cupular system (as compared to preflight level) to an adequate stimulus (rotation in a chair with the eyes shut, while making precisely graded head movements), as demonstrated in studies conducted during the 28-84-day missions on the Skylab program [27]. These studies started on the 8th day of the flight, i.e., at the time of termination of primary adaptive reactions. The demonstrated differences in reactions to vestibular stimulation in flight and on the ground are apparently related to change in function of otolith receptors, since stimulation of the semicircular canals was the same in flight and on the ground, while visual stimulation was precluded in both instances by shutting the eyes. The authors believe that weightlessness could lead to attenuation of the modulating effect of the otolith system on receptors of the semicircular canals.

Impairment of Interaction of afferent Systems Involved in Spatial Orientation

We know from the fundamental studies of I. P. Pavlov [15] and L. A. Orbeli [13, 14] that integration of information going to the central nervous system, which determines interaction of afferent systems, is one of the basic mechanisms of the body's reactions to environmental stimuli. This thesis has been confirmed also in several subsequent studies [12, 22].

As indicated by G. A. Komendantov and V. I. Kopanev [9], spatial orientation is effected due to the functional continuity of activity of several analyzers (vestibular, visual, proprioceptive and others). Disruption of this continuity could lead to onset of unusual reactions, including MS symptoms. M. D. Yemel'yanov and A. G. Kuznetsov [7] proved experimentally that the thresholds of vestibulovegetative reflexes can be lowered under the effect of stimulation of the visual or proprioceptive system, which served as concrete confirmation of the role of impairment interaction of analyzer systems in the mechanism of MS development.

Sensory conflicts. At the present time, onset of sensory conflicts (Table 2) in the form of passage from different sensory systems of information that is inconsistent to previously formed integral sensory image based on experience, which reflects a certain position and shift of the body in space, is considered to be one of the causes of motion sickness [31, 34]. The most importance is attributed to visual-vestibular and canal-otolith conflicts [10, 31, 34].

The hypothesis on the role of otolith asymmetry in development of MS in and after flight is a special case in theory of sensory conflicts [6, 25].

According to this hypothesis, the existing congenital differences in weight of the left and right otoliths are compensated by the central nervous system, which makes it possible to make up for the shortage of information in the lighter otolith. In weightlessness, such compensation is inappropriate, since there are no weight differences between the otoliths, while the compensating factor leads, in this case, to asymmetry of impulsation from the right and left otoliths. As a result, there is development of vertigo, eye movements and change in posture, which last until the "compensatory center" adjusts to the new situation.

Table 2. Some sensory conflicts that develop in weightlessness

Ground-based conditions (normal)	Spaceflight (sensory conflict)
1. Interotolith interactions	
With change in head position there is corresponding change in impulsation from otoliths.	With change in head position there is no change in impulsation from otoliths.
2. Asymmetry of vestibular system	
Congenital asymmetry of vestibular system (including that resulting from difference in otolith mass on the left and right) is well-compensated in the course of ontogenesis by stable functional continuity of analyzers.	Change in analyzer interaction causes decompensation and manifestation of vestibular asymmetry.
3. Interaction of visual and canal-otolith system	
Both systems deliver signals about position of the body in relation to spatial coordinates.	Visual system gives adequate signals about body position in relation to spatial coordinates, while those from canal-otolith system do not conform to visual system signals.
4. Interaction of visual system and nonlabyrinthine mechanoreceptors perceiving force of gravity	
Visual system, proprioceptors, mechanoreceptors of viscera and integument give adequate signals about body position in relation to spatial coordinates.	Visual system gives adequate signals about body position in relation to spatial coordinates, while signals from mechanoreceptors do not reflect actual position of body in space.

Upon returning to earth, the functional continuity developed in weightlessness is disrupted and (due to differences in otolith weight) there is a dysbalance between impulsation from the right and left labyrinths, which leads to development of vestibular disturbances. Thus, individuals with greater otolith asymmetry are more susceptible to MS. In weightlessness, asymmetry of otolith

afferentation can occur not only due to loss of otolith weight, but as a result of differences that arise in efferent impulsation to the right and left labyrinths [11].

L. N. Kornilová et al. [11] conducted special investigations to determine the relationship between vestibular asymmetry and predisposition to MS. With artificial production of asymmetry by means of unilateral galvanization of a labyrinth, provoking factors reliably ($P<0.05$) lowered resistance to MS. The authors also demonstrated that lower resistance to MS was observed in subjects with markedly asymmetrical reaction of counterrotation of the eyes than in those with symmetrical reaction. It should be noted that most cosmonauts presented transient spontaneous nystagmus after long-term missions, and reliable vestibular asymmetry, including eye counterrotation reaction, was demonstrated in the postflight period in all cosmonauts who participated in missions lasting 75 to 211 days (12 people).

Distinctions of formation of functional system of statokinetics and spatial orientation in weightlessness. Theory of sensory conflicts can be interpreted from the standpoint of the conception developed by P. K. Anokhin of a functional system as the aggregate of different nerve centers and peripheral organs united into a single whole by an adaptive result that is useful to the body, which this system creates [1-3]. In this case, a useful result is providing for adequate statokinetics and spatial orientation of the body in weightlessness during different types of activities, which is vital to existance under these conditions and maintenance of homeostasis in the broad sense of the word.

Formation of the functional system of organization of statokinetics and spatial orientation under ordinary living conditions is probably governed by the common laws of formation of functional systems, and it has several stages.

In this case, afferent synthesis consists of interaction in the central nervous system of afferentation signaling spatial body position that originates from the exogenous and endogenous environment (situational afferentation). Taking into consideration the body's requirements at a given time (dominant motivation), situational afferentation and prior experience acquired through evolution and individually, a decision is made in the nerve centers, as a result of which there is formation of a specific program of actions to preserve or alter statokinetics and spatial orientation. There is blocking of the connections of nerve center neurons that are not aimed at reaching the set goal.

Then there is development of the stage of efferent synthesis when, in accordance with the program of action, neurons are triggered that implement the body's integral reaction, which provides for assuming the necessary position and orientation in space.

At the same time, a system is formed in the central nervous system for anticipation and evaluation of the results of action (acceptor of action results), which compares results of action to the prediction; if they do not coincide, the functional system changes and ultimately a result that is beneficial to the body is achieved.

In weightlessness, because of the change in nature of afferentation and onset of sensory conflicts, already at the stage of afferent synthesis unusual situational afferentation is delivered to the central nervous system that is not recorded in memory mechanisms, since the body had not encountered this unique situation before in phylogenesis and ontogenesis. For this reason, at the decision-making stage there may be difficulties in formation of the program of action. In this unique situation, the body will perhaps have one (not necessarily optimum) degree of freedom, which could lead to realization of both an adequate and inadequate adaptation result. If an inadequate result is obtained in the existing situation, some time will be required to gain individual experience, search and choose the optimum form of useful adaptive result. It is known that the disturbances in spatial orientation that develop in spaceflights are relatively brief, while negative reactions disappear within 2-3 days to a week.

The hypothetical order of formation of the functional system that organizes statokinetics and spatial orientation on earth and in weightlessness is shown in Table 3.

Thus, analysis of statokinetic and vestibular functional disturbances arising during spaceflights, which was made on the basis of the conception of P. K. Anokhin, indicates the possible routes for preventing these disturbances. One of them is to refamiliarize the body with the unique conditions of weightlessness (with respect to change in afferentation), which can be done by brief exposure to weightlessness (aircraft flights following Kepler's parabola) or participation in actual spaceflights. It is known that several cosmonauts who presented MS symptoms during their first spaceflight presented less marked symptoms in subsequent ones.

Status of hemodynamics during flight and vestibular disturbances. At the present time, changes in hemodynamics and fluid-electrolyte metabolism are viewed as contributory factors in development of vestibular disturbances during spaceflights.

Changes in fluid-electrolyte metabolism and its regulation at the first stage of flight (1st week) are characterized by general fluid loss, increased excretion of salts and antidiuretic hormone (ADH) in urine [32]. Thereafter, in the presence of increased excretion of potassium, sodium and aldosterone in urine, there is a tendency toward decrease in ADH excretion.

These changes in hemodynamics and fluid-electrolyte metabolism coincide with development of vestibulovegetative disturbances. In this reagard, I. I. Bryanov et al. [4] believe that the described sets of hemodynamic and vestibulovegetative manifestations are interrelated. They indicate that hemodynamic disturbances associated with microcirculatory disorders on the tissular and intercellular levels, as well as impaired fluid-electrolyte metabolism, are the initial background for development of vestibulovegetative disorders in spaceflight. The authors back up their hypothesis also with the well-known (from clinical observations and investigations) correlation between state of hemodynamics and stasis in the brain, as well as vestibular function. In addition, the authors observed vestibular disturbances during clinostatic and antiorthostatic hypokinesia. However, as indicated by B. I. Polyakov [17], special investigations must be conducted during spaceflights with controlled change in degree of blood redistribution to validate the hypothesis of correlation between hemodynamic and vestibular disturbances.

Table 3. Functional system of formation of statokinetics and spatial orientation on earth and in weightlessness (hypothesis)

On earth	In weightlessness
Causes of formation	
Effect of gravity and change in body position when working, during locomotion, assuming different positions, etc.	Change in body position when working, in locomotion, assuming different positions in the absence of gravity
Stage of afferent synthesis	
Comparison, selection and synthesis in CNS of afferentation from external and internal environment and giving signals about statokinetics and body position in space (dominant motivation, situational afferentation about real living situation, memory mechanism)	Onset of sensory conflicts and change in nature of afferentation, which leads to delivery to CNS of situational afferentation characterizing the unusual external and internal environment which was not fixed by memory mechanisms in phylogenesis and ontogenesis
Stage of decision making	
Blocking in the central apparatus of the functional system of the diverse functional associations unrelated to achievement of the needed goal (providing for statokinetics and spatial orientation adequate to prevailing conditions), formation of program of actions and system for evaluating results (acceptor)	Difficulty in formation of purposeful program of actions ("uniqueness of situation," as reported by situational afferentation and absence of a model of this situation in "memory")
Stage of efferent synthesis	
Triggering of locomotor and autonomic components under the influence of efferent commands determined by the program of actions, which lead to assumption of a specific position, implementation of necessary locomotion and orientation in space	In the "unique situation," the body may perhaps have one (not necessarily optimum) degree of freedom, which could lead to realization of adequate and inadequate adaptive results
Results of action (feedback)	
By means of feedback the parameters of the obtained result (statokinetics and spatial orientation) are fed in the CNS to acceptor of result and compared to prognosis. In the event of mismatch the structure of the functional system changes and ultimately a result that is useful to the body is achieved.	When the obtained result is inadequate in the existing situation, the body will require some time to acquire individual experience, search and select the optimum form of useful adaptive result.

Status of endocrine functions and predisposition for MS. The results of special investigations [30] revealed that blood levels of adrenocorticotropic hormone (ACTH), ADH and thyrotropic hormone are about twice as high in subjects with high resistance to MS than in those with low resistance.

As we have already noted, under spaceflight conditions ACTH level in plasma declines and cortisol content increases, which could also contribute to the decline in resistance to MS.

In the 22 years that have elapsed since man's first flight into space, many data have been accumulated concerning man's reactions to spaceflight. Importance was attributed to investigation of MS that occurred with the change to weightlessness. However, in spite of this, there is still no generally accepted hypothesis to explain the mechanism of onset of vestibulovegetative disturbances in weightlessness [8]. There are no tests for reliable prediction of the possibility of MS during spaceflights. The existing agents for prophylaxis and treatment of MS in weightlessness do not permit effective prevention or arrest of symptoms of space MS.

Of all the hypotheses concerning the nature of onset of MS, the most validated one at this time is the hypothesis of impaired interaction of afferent systems that form the conception of the body's orientation in space. This disturbance is manifested by onset of sensory conflicts, which may be classified as follows: interotolith conflicts, canal-otolith conflicts, conflicts between visual and vestibular systems, conflicts of visual system and nonlabyrinthine mechanoreceptors perceiving gravity, conflicts arising with manifestation of asymmetry of the vestibular system as a result of decompensation.

The distinctions in formation of the functional system (in the interpretation of P. K. Anokhin) of statokinetics and spatial orientation could be of prime significance in onset of the set of MS symptoms in weightlessness. Perhpas, these distinctions are manifested by delivery to the central nervous system of situational afferentation characterizing the unusual exogenous and endogenous environment when the body is exposed to weightlessness, that has not been imprinted by memory mechanisms in the course of phylogenesis and ontogenesis. The unique situation about which situational afferentation sends signals and absence of a model of this situation in "memory" make it difficult for a program of action to be formed. All this could lead to an inadequate adaptation result and, consequently, to a search for an optimum decision by running a chain of results. Evidently, some time will be required to acquire individual experience, search and select the optimum form of reaction.

Such factors as change in hemodynamics and hormonal status are also predisposing factors instrumental in development of symptoms of MS.

Apparently, re-exposure to weightlessness, as well as conditioning for redistribution of blood, are the most promising direction for prevention of vestibular disturbances during spaceflights. It is also quite important to refine methods of screening on the basis of demonstration of physiological mechanisms of individual predisposition for MS. Apparently, the most important aspects of the problem of space MS would be resolved mainly by conducting specific investigations during actual spaceflights. It is becoming particularly important to make a quantitative evaluation of otolith and semicircular canal functions under the effect of adequate, graded stimuli during spaceflights.

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EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

UDC: 629.78:612.821-08

PSYCHOPHYSIOLOGICAL DISTINCTIONS OF ORGANIZATION AND REGULATION OF DAILY CYCLOGRAMS OF CREW ACTIVITIES DURING LONG-TERM SPACEFLIGHT

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 10 Jul 84) pp 12-16

[Article by A. N. Litsov and V. F. Shevchenko]

[English abstract from source] This paper presents the results of analysis of work-rest cycles of the Salyut-6 and Salyut-7 prime crewmembers. The distribution of work-rest cycles within the day, week, month and the flight as a whole, their relation with other components of the time schedule, the effect of various factors involved on the health status and work capacity were studied. It was shown that specific work-rest cycles should be rigorously adhered to. It was demonstrated that proper planning and realization of work-rest cycles, as well as their correction during actual flight with respect to psychophysiological and biorhythmological variations are required to maintain good health condition and high work capacity of crewmembers.

[Text] According to data published in the Soviet and foreign literature [1, 6, 12, 14], successful performance of complicated and diverse tasks during spaceflights is related directly to the effect on cosmonauts of the set of factors of their new environment, including an unusual work and rest schedule (WRS), which involves essentially compulsory organization and regulation of the crew's activities for a long period of time. It has been established that a strictly regulated WRS imposed on crews in flight provides for reliable and effective performance in some cases (following the customary ground-based schedule) [1, 6, 7, 14] and leads to marked functional deviations and changes in cosmonauts' work capacity, to the extent of disruption of the flight program in other cases (use of shifted, split and floating schedules) [6, 16]. Evidently, organization of optimum WRS with consideration of the factors that affect cosmonauts during their activities should be considered one of the effective means of assuring reliability of crew performance aboard a spacecraft.

We shall discuss some of the sleep and waking cycles used at the present time during long-term spaceflights, as well as distinctions of organization and regulation of crew activities in the course of a work day throughout a mission, using the cyclograms of crew activities during the main missions of Salyut-6 and Salyut-7 stations.

Organization of cyclogram of crew activities as related to time of day (in day and night rhythm). According to data in the literature [1, 2, 14], the dynamics of man's functional state undergo fluctuations in a 24-h period that coincide with the change from night to day (maximum activity in the daytime hours and minimum at night). In actuality, there are changes in reliability and efficiency of professional performance, as well as in numerous functions of the body in strict accordance with these fluctuations [2, 4, 5, 13, 15]. Peak activity on the usual schedule is observed in the middle of the waking period (3d-8th hours), whereas it is considerably lower at other times (1st-3d and 9th-15th hours). Use of other WRS (shifted, split, migrating) [1, 7, 13, 14] for the performance of the same work is associated with uneconomical expenditure of nervous and muscular energy, as well as faster development of fatigue. Thus, physiologically the customary ground-based schedules are the most advantageous, since only they can provide all of the conditions for efficient performance at minimal expenditure of energy and less marked fatigue.

As shown by analysis of flight data, the crews of the main missions aboard Salyut-6 and Salyut-7 stations followed schedules in space involving 24-h alternation of sleep and wakefulness (70-80%), which coincided in parameters to the usual "Moscow" schedule [8, 10]. Only some of the WRS used in flight (19-30%) differed in both duration (shorter or longer cycles) and in phase (right or left shift of cycles in relation to Moscow time). Depending on the nature of the initial change in sleep-waking cycles, four groups could be distinguished: schedules with shorter and longer waking periods; with shorter and longer sleep periods [8]. In virtually all flights, we encountered most often schedules with initial curtailment of the waking period (36%) and its extension (30%), and considerably less often schedules with shorter (16%) and longer (16%) sleep periods. It was established that a change in sleep-waking schedule led to deviations of functional state and work capacity of all crew members (according to subjective evaluations). The magnitude of these deviations was directly related to the extent and direction of shifts in sleep-wakefulness and changes in proportion of each.

As we know [1, 7, 9], the greater the sleep-waking shift in the WRS, the worse it is tolerated by man and the longer adjustment to it. Analysis of crew cyclograms made for this factor revealed that, although the magnitude of sleep-waking shifts fluctuated over a wide range (up to 9 h), duration did not exceed 1-2 days, which attenuated disturbances related to the effect of this factor. Thus, for the crew of Salyut-6, shifts in the sleep-rest cycles exceeding 3 h were encountered in only 27.9% of the cases, and they lasted for no more than 1.5 days. For the crew of Salyut-7, schedules with more than 3-h shifts in sleep-rest cycles of the same duration were observed in only 15.4% of the cases.

The degree of negative effect on man of shifts in work-rest cycles depends not only on their magnitude, but direction. According to some data [7, 11, 14], the most difficult change is a shift to the left on the time scale in sleep-waking cycles. Out of the total number of cyclograms analyzed in flight, a left shift was encountered in crew members even more often than a right one (by 10-20%), which apparently indicates that there was some intensity of performance cyclograms, particularly during periods of using maximum loads

Table 1.
Distribution fo WRS as a function of magnitude and direction of shift in sleep-waking cycles of crew of first main mission (FMM-1) aboard Salyut-7 station

Months of flight	Number of days analyzed	Days with left shift			Days with right shift		
		under 3 h	over 3 h	total	under 3 h	over 3 h	total
1	27	2	—	2	4	—	4
2	28	—	1	1	2	—	2
3	30	—	1	1	4	2	6
4	30	1	1	2	1	—	1
5	30	2	—	2	3	—	3
6	31	6	1	7	1	—	1
7	26	—	—	—	7	—	7

(Table 1). One can also assess the intensity of daily cyclograms during these periods by the duration of sleep intervals. As we know [4, 7, 17], sleep is the main function in determining the optimality of any WRS. Analysis of daily cyclograms revealed that the time planned for sleep constituted a mean of 8-9 h for the duration of the mission, but on some days (after performing important and time-consuming work and experiments, on days off, etc.) it reached 9-11 h.

Thus, from the foregoing we see that, in spite of the wide diversity of daily cyclograms of crew activities during long-term flights, the vast majority coincides with the schedule that is customary on the ground, while the shifted and floating WRS followed on certain days are only used for a short time (no more than 1-2 days).

Cyclograms of activities as related to dynamics of crew's work capacity in the course of the work day. Results of investigations [?, 9, 13] indicate that man's efficiency can change during work, not only in the biorhythmological aspect (circadian schedule), but under the influence of the work itself. Four main stages are distinguished: breaking in (30 min to 1 h); high stable efficiency (60 min to 2 h); compensated stable efficiency (2 to 4 h) and lower efficiency (over 4-6 h).

As shown by analysis of inflight cyclograms, professional activities of the crew during the work day is of two varieties: basic work zone (work for a specific length of time) and sporadic work performed at different waking periods. The basic work zone is the set of operations making up the main content of the program for a given flight day (scientific experiments, dynamic operations, repairs, etc.). Sporadic activity refers to daily operations to check station systems, engage in communications, self-service, etc. As we know [3, 10], total waking time also includes time for personal hygiene (30-60 min), preparation and intake of food (110-120 min), physical exercise (130-150 min) and other necessities. For this reason, evaluation of appropriateness of professional activities should be made with consideration of three main parameters: total work time, its distribution over the entire waking period and proportion in relation to other elements on the schedule. As shown by analysis of cyclograms, overall duration of work activities fluctuated over a rather wide range at different stages of spaceflight, from 195 to 465 min. One can distinguish five variants of schedules, depending on distribution of activities over the waking period: 1) with nominal distribution of the main work zone (starting work 1-1.5 h after sleep and ending in the 11th-12th h of being awake); 2) with uniform distribution of work over the entire waking period (starting work immediately after awakening and ending in the 14th-15th h of the waking period); 3) with a shift of basic work zone and all professional activities to the early waking hours; 4) with a shift of main work zone to

the second half of the w..king period; 5) with two work zones in the first and second halves of the waking period, and a rest period between them.

The 1st (36%) and 4th (30.2%) schedules were encountered the most often in the flight cyclograms. Schedule 3 was used in 20.4% of the cases and schedule 2 in only 12.6%. Schedule 5 was used the least (less than 1%). Of the five variants, one should apparently consider the first the best; it allows the crew to become gradually involved in activities and provides conditions for proper rest after work. On this schedule, peak work activity coincided with the dynamics of the circadian stereotype. The other variants are less desirable, since they require greater strain on physiological systems, which could (with large enough loads) be an additional source of development of fatigue.

No doubt, an important indicator of the quality of professional activity is its proportion in relation to other elements on the daily schedule, as determined by the work load index:

$$I_{WL} = -\sum_{i=1}^{m} \frac{t_i WL}{t_i W},$$

where t_iWL is duration of work in ith time segment; t_iW is duration of waking period in ith time segment; m is number of analyzed time segments. This parameter reflects, on the one hand, the share of the period of professional work in the entire waking period and, on the other hand, intensity and strain of crew performance during work day, week or month. According to the results obtained (Figure 1), the crew's work load was small at virtually all stages of flight and constituted 0.35-0.42. Nevertheless, in some flight periods the index rose drastically in comparison to the mean for the flight. As shown by analysis, this rise is attributable to different causes. Thus, during the 1st week of flight, the large load is attributable to work on reactivating the station, performing check tests, preparing equipment, etc. In the 6th week (cross-hatched segment 1 of graph) the crew was preparing for a rendez-vous and received the first visiting expedition and in the 15th week (segment 3), the second one, performing joint experiments and studies with them as provided by the program. Segment 2 corresponds to the extravehicular activity program. The main work in the 23d week (segment 4) consisted of a series of astrophysical and technological experiments, as well as work with the Piramig equipment. Yet, as can be seen in Figure 1, even during these periods the index for the work week did not exceed the standard value.

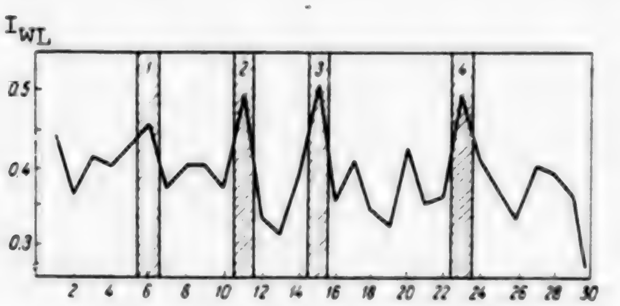

Figure 1.
Dynamics of planned work load (according to load index) during 211-day spaceflight
X-axis, weeks of flight
1-4) flight phases (explained in text)

Thus, according to the material we have discussed, distribution of the crew's professional activities in the course of the work day and its intensity, as

assessed by the I_{WL}, conformed to the standards and requirements adopted in industrial psychophysiology. This was corroborated by the successful fulfillment of the flight program and large amount of work done at the crew's initiative in their free time.

Organization of cyclogram of crew activities with consideration of spaceflight duration. As sh wn by analysis of flight data, the typical distinctions in 24-h cyclogr ms of activities of members of all crews, as spaceflight duration increased, were: gradual change in proportion of sleep and waking cycles, in the direction of increase in total sleep time, gradual decline of work load and alteration of weekly work and rest cycles.

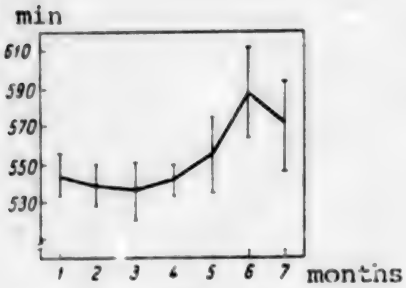

Figure 2.
Planned duration of sleep as a function of duration of flight
X-axis, months of flight.
Boldface curve--mathematical expectation (min); vertical segments--confidence intervals for 5% significance level

Table 2.
Dynamics of duration of work day, work load index and its distribution throughout waking period as a function of duration of spaceflight ($M \pm m \cdot t$)

Flight month	Work week, days	I_{WL}, arbitrary units	T_{p_1}/T_{p_2}
1	5.8±1.5	0.4±0.01	0.88±0.12
2	7±5.2	0.42±0.02	0.81±0.12
3	4±1.0	0.38±0.02	1.54±0.43
4	5.2±3.5	0.42±0.03	1.28±0.18
5	4.6±0.8	0.36±0.02	1.06±0.12
6	5.2±1.0	0.4±0.03	0.76±0.05
7	4.8±0.5	0.34±0.04	1.29±0.11

Key:
- M) mathematical expectation
- *m*) mean error
- *t*) Student's criterion for 5% significance level

T_{p_1}, T_{p_2}) work time in 1st and 2d half of work day

We see from the data listed in Figure 2 that the proportion of sleep and waking periods in the cycles held at about the same level for the first 2-3 months of of FMM-1 aboard Salyut-7 station. Starting with the 4th month, the time allotted for sleep gradually increased, reaching an average of 589±24 min by the end of the 6th month. The opposite pattern is observed for the work load index. According to Table 2, in spite of being obviously fluctuating, the work load presented a distinct tendency toward decline as flight duration increased, apparently reflecting general decrease in the crew's activity, on the one hand, and increase in volume of other elements on the schedule (physical exercises, sets of preventive measures, etc.), on the other hand. Starting with the 2d-3d month of flight, the load shifted drastically to earlier stages of the waking period (see Table 2). A rather distinct dependence is also manifested in the nature of regulating the weekly cycles. According to the material analyzed (see Table 2), we see that there is gradual regularization of proportion of work days and days off (5 work days and 2 off), whereas with addition of one more medical day (which is not entirely a work day), the proportion shifts in the direction of fewer work days.

Thus, with increase in duration of spaceflights, there are gradual changes in organization and regulation of

the crew's daily activities, with decline in volume and intensity of work and increase in share of preventive elements on the schedule, which apparently provides for better preparation of the crew for descent from orbit and subsequent recovery measures.

To sum up all of the material we have discussed, it can be concluded that the following is recommended to assure reliable and efficient crew performance in space: use of appropriate sleep-waking schedules (two variants, one of which is the customary earth-based one and the other is altered and used for a short time); realistic planning of professional activities during work day and its conformity at all phases of the flight to psychophysiological and biorhythmological characteristics of cosmonauts; uniform distribution of work and rest periods for the crew in the course of the day, work week, month and mission as a whole. The results of prior flights indicate that wise planning of daily cyclograms of inflight crew activities is an effective measure, that permits solving complex problems and maintaining a high level of functional capacity in the cosmonauts, regardless of flight duration.

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UDC: 629.78:612.821

OPERATOR'S FUNCTIONAL COMFORT ZONE WHEN CONTROLLING MOVING OBJECT

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 27 Oct 83) pp 17-19

[Article by V. I. Myasnikov, B. N. Ryzhov and V. P. Sal'nitskiy]

[English abstract from source] Objective evaluation of the psychic strain of six operators who performed multiparameter compensatory tracking of the moving object helped to identify the zone of changes of its basic parameters. The control within this zone required a minimum psychophysiological cost (zone of functional comfort). The control beyond this zone was associated either with information overload or with a dramatic increase of the risk of failure. In five operators this led to a significant aggravation of the psychic strain. This study has shown that special identification of the zone of functional comfort in the design of data display devices may be a method of optimizing man's work in the ergatic systems.

[Text] The problem of predicting the functional state of an operator has an important engineering psychology aspect, which is related to development of ways and means of optimizing his working conditions in ergatic control systems. This aspect acquires particular importance when solving problems related to control of dynamic objects (DO), as is the case in aviation, space and other areas of applied psychophysiology [2]. This is attributable primarily to several specific working conditions of DO operators. For example, a typical task for them is time and space maneuvering, in the course of which the controlled object could perform any evolutions meeting only one requirement, that the controlled parameters be within the range of areas that provide for technical reliability of the system. The nature of control actions is not rigidly determined, and it is largely related to the subjective distinctions of an operator, the main one being his professional knowhow. At the same time, the adequacy of the conceptual model of the work and choice of control tactics are rather important to formation of the operator's functional states and, consequently, to prediction of reliability of the system as a whole [1, 5, 7, 8].

One of the means of optimizing the performance of a DO operator could be the choice and validation of control zones that are the most beneficial to him from the standpoint of consideration of his psychophysiological expenditures,

and appropriate identification of these zones in information display systems [1, 3]. For this reason, our objective here was to assess the mental strain of an operator and define functional comfort zones (FCZ) while performing tasks of reciprocal maneuvering of manned DO.

Methods

These studies were conducted on a simulator complex, which consisted of the operator's work place equipped with an information display system and manual controls, analog-digital computers on which a system of differential equations was realized concerning DO movement and algorithms for evaluating operator performance and his psychophysiological state; mechanical stand for linear and angular displacement of DO; equipment for medical monitoring, etc.

In the course of the study, the operator was in a cabin, performing multiparameter compensatory tracking of the DO attached to the stand for 20 min. The range of permissible values of controlled parameters, beyond which performance was qualified as failure, was given to the operator by means of special sighting devices. Probability of failure (P_f), considering the normal nature of the law of distribution of current values of parameters of motion to be controlled, was determined for each minute of work using the following formula:

$$P_f = 1 - \prod_{i=1}^{n} \left[2\Phi\left(\frac{\sigma_i^{max}}{\sigma_i} \right) \right].$$

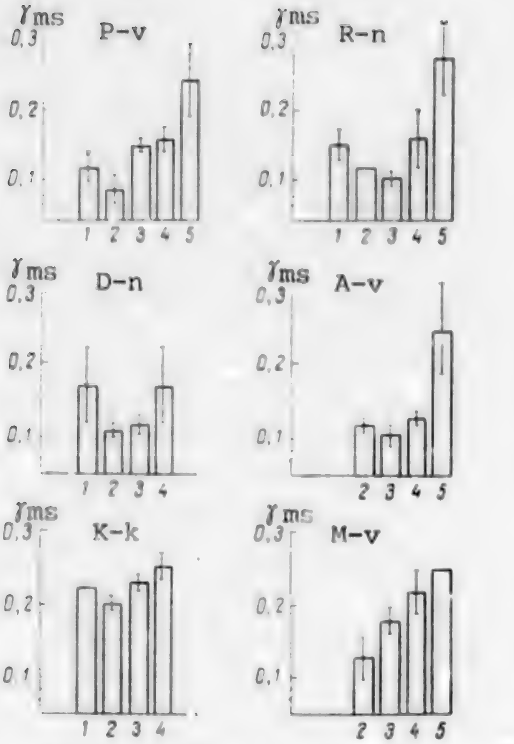
where σ_i is standard deviation of ith controlled parameter to normal level (control errors), σ_i^{max} is maximum permissible deviation of this parameter and ϕ is a Laplace function.

Evaluation of the operator's functional state was made using a method proposed by us [6], determining the integral parameter of mental tension (γ_{ms}) for each minute. Calculation of γ_{ms} was made on the basis of combined analysis of psychophysiological parameters: heart rate, electrical activity of the brain in the range of frequencies corresponding to Θ- and β_2-waves on the EEG, level of involuntary muscular activity.

The study was conducted on 6 essentially healthy male operators 24-40 years of age who had undergone a clinical examination. The operators performed a total of 36 test sessions of control work.

Results and Discussion

In the course of the study we established the level of operator's mental strain as a function of performance in DO control task (see Figure). As can be seen from the illustrated charts, the lowest mental tension was observed when controlling a DO with failure probability P_f = 0.4-0.6. An increase in probability of failure was associated with appreciable rise in specific increment of γ_{ms}, which constituted 0.07-0.2 AU [arbitrary units] per 0.1 P_f; the absolute values of mental strain parameter exceeded the man for each operator by 2 or more times.



Level of mental tension as a function of probability of failure in six different operators performing task
X-axis, probability of failure, 1,2,3,4,5 correspond to P_f ranges of 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, respectively; y-axis, mental tension level, γ_{ms} (in arbitrary units)

Analysis of the results leads us to note that, in a number of instances, the fact that the DO came close to the boundaries of the range of permissible values was not interpreted by experienced operators as a threat to successful performance of their task. An important role was played by the vector of velocity of the object, and the situation was considered critical only when, along with a short distance to the limits of permissible values, the object continued to move in the unfavorable direction at increasing speed. B. F. Lomov [4] had also observed a tendency by experienced operators to control the vector of velocity, rather than vector of the object's position. Nevertheless, a significant increase in parameter of mental tension in the range of P_f = 0.7-1 (see Figure) and concomitant changes in psychophysiological parameters--increased variability of pulse rate, increased overall energy of Θ-waves in the EEG spectrum with concurrent depression of β_2-waves--were indicative of development under these conditions of emotional reactions related to subjectively critical rise in risk of failure.

A tendency toward increased mental tension was also noted with relatively low (0-0.3) probability of failure in performance of the task. This tendency was the most noticeable in individuals who had much experience in operator work (see Figure, D-n and P-v), and who had repeatedly participated in such studies. Having a significant stock of control skills, these operators could control with relative ease the parameters of DO movement without exceeding the range of permissible values; they considered their task to be the achievement of maximum quality of control working at the limit of capacities. The fact that success in performance of the task was viewed as evidence of their professional skill also was instrumental in the choice of extreme work modes corresponding to redistribution of tactical means of reaching their goal. However, the desire to work in an area below the working threshold was associated with a number of unpleasant circumstances: under such conditions, there was noticeable increase in load on the visual analyzer, since the operator had to look more closely at the object to fix its barely noticeable deviations from the base position, there was increase in work pace and number of micro-readjustments of parameters. All this led to a situation where an effort to further improve precision of control of different parameters led to unwarranted increase in number of control operations, leading to excessive fuel consumption, i.e., ultimately to worsening of performance quality.

In addition, muscular rigidity that develops with increase in mental tension led to impaired measurement and coordination of motions, increased inconsistency of handling controls, change from smooth control movements to movements in bursts or dashes which made the process of DO control difficult. Equally important is the fact that an inadequate level of mental strain associated with work in the subliminal region led to distinctive rigidity of sets when selecting control procedures, to degradation of tactical skill. The operators actions grew increasingly stereotypical with emphasis on control of the most frequently and rapidly changing parameters. Changes in other parameters often remained unnoticed for a long time, which led to the system to an irregular operating mode.

Thus, in the course of this study it was shown that when performing tasks of time and space maneuvering of DO, retention of both excessively large and excessively small controlling error leads to the same result: increased psychophysiological expenditure by the operator and decreased reliability of the system as a whole. Here, the level of mental strain emerges as a criterion use of which makes it possible to define appreciably conceptions about the size of the optimum range of DO control. An example of such a range under the concrete conditions of our study was the above-mentioned operator FCZ--the values of controlled parameters corresponding to the P_f range of 0.4-0.6 limited by the zone of increased risk, on the one hand, and zone of information overload, on the other.

To sum up the results of this study, we should mention the need for purposeful formation in operators of conceptions concerning the FCZ range (its mean statistical characteristics) and recommendation of special measures--use of adaptive control circuits, FCZ indication in information display systems, appropriate instructions, etc., the purpose of which would be for the individual to be more fully aware of his psychophysiological capabilities when working in complex ergatic systems.

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UDC: 629.78:612.821-08

RAPID DETERMINATION OF CADET DISCIPLINE BY PROJECTIVE TESTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 20 Apr 84) pp 20-23

[Article by V. I. Yevdokimov]

[English abstract from source] The reliability of rapid prediction of the disciplined or undisciplined behavior of cadets using selected projective tests (modified apperception test, Rosenzweig test of picture frustration, Zondi test) was investigated. The tests were performed on 50 certified pilots and 400 cadets. By means of correlation and factor analyses the references given to the cadets by their seniors were compared with the results of the projective tests. It was found that the modified apperception test can be used to evaluate cadet's behavior within a comparatively short time. Marked extrapunitive trend combined with self-defense type of solution of the Rosenzweig test diminished the conformity of the personality and facilitated the development of conflict situations and undisciplined acts. The undisciplined cadets preferably selected pictures of seriously ill patients with epilepsy, catatonia or hysteria. These probability characteristics help to distinguish the cadets that need specific attention and supervision.

[Text] In recent times, much attention has been given to investigation of personality distinctions of pilots and cadets [1, 2, 9, 3, 7, 10]. However, information about the basic sociopsychological traits of applicants to flying school--discipline, social activities, etc.--is still not being used sufficiently for this purpose. We explored the possibility of using certain projective tests to predict discipline of pilots and cadets.

Methods

1. The flight variant of the thematic apperception test (TAT) consisted of 10 pictures reflecting aviation topics, which enabled us to assess some social attitudes: flight motivation, confidence in successful achievement, general sthenia, anxiety, discipline, etc. [18].

Before the test, the subjects were instructed as follows: "This is a test of imagination. Make up a story for each picture, without describing the picture itself. Answer the following questions: 1) What led to the events depicted in the picture? 2) What is happening at the depicted moment? Who are these people? 3) What is the outcome of the situation? Do not think too much about the accuracy of the story. Every story is quite correct. You are allowed 5-7 min to make up a story for each picture; first think about answers to the questions for 1-2 min and then write them down."

We considered the conception of a story as a model of the subject's activities as the general theoretical system for interpretation of the TAT story.

Test results were interpreted on special forms. On the left side of the form, there was a list of the tested psychological parameters. In the middle and on the right were picture numbers, under which the corresponding psychological traits were scored. The scores were then added and a mean parameter was calculated.

Discipline of the main characters in the TAT pictures was scored on a 9-point scale. We assessed discipline of the subjects analogously, on the basis of characteristics provided by commanders and experienced methodologist-pilots in a conversation (Table 1).

Table 1. Evaluation of cadet discipline

Score	Criterion
9-8	Main character of TAT story (cadet) is a highly disciplined personality. He comprehends correctly flying rules and moral standards, adheres to them himself and restrains undisciplined actions of others. One of the best flying cadets in the unit.
7-6	Disciplined personality, capable of properly judging inadmissibility of undisciplined actions. One of the best cadets in the flight group.
5-4	Main character of TAT story (cadet) may infract flight discipline, preflight rest schedule, elements of flight assignments, for which he has been punished.
3-2-1	Main character of TAT story commits gross undisciplined deeds, breaks flight laws and disrupts flight assignments bordering on (or ending with) a flight accident. Is an undisciplined cadet. He has often been called to the school council for this. Dismissed from flying school for lack of discipline.

2. Rosenzweig's picture frustration test consisted of a set of 24 pictures. The personages depicted on the left of each picture utter words that describe frustration. There is a blank box above the person on the right for an answer.

Each answer by the subject was rated from the standpoint of direction and type of reaction. The following directions of reactions were distinguished: 1) extrapunitive--subject's reactions aimed at animate and inanimate surroundings;

2) intrapunitive--frustration aimed at oneself; 3) impunitive--frustation consider of little significance or something that can be corrected if one thinks about it and waits. The following types of reactions were singled out: 1) ego-defense--with fixation on self-defense; 2) obstacle-dominance--with fixation on obstacle; 3) need persistence--with fixation on satisfaction of needs. The combination of these 6 categories yiels 9 possible rating factors [4, 10].

3. Szondi test. A total of 48 photos of mental patients arranged in 6 series was used as stimulating test material. In each series there were 8 forms of psychopathology (epilepsy, hysteria, catatonia, paranoia, sadism, homosexuality, mania, depression) that were given a psychological interpretation.

During the examination, a series of 8 photos was presented at the same time. The subject had to quickly select, as his first impression, 2 photos that he liked and 2 that he disliked in each series. The results were expressed in the form of a graphic representation of the object, profile, consisting of 8 factors that had positive and negative connotations.

Results and Discussion

First, on the basis of the TAT material, we calculated the average score for discipline of leading characters in the pictures, which could be interpreted as the attitude toward discipline of applicants (n = 174), first (n = 89), second (n = 68), fourth (n = 84) year cadets and pilots (n = 53).

Table 2.
Mean indicators of attitude toward discipline of TAT picture protagonists ($M \pm m$)

Group	Discipline
Applicants	4.97±0.34
First year cadets	6.15±0.35
Second year cadets	6.58±0.39
Fourth year cadets	7.25±0.43
Pilots	6.75±0.42

Analysis of stories in the TAT variant revealed the most marked indicators of indiscipline in applicants. The protagonists of their stories committed undisciplined acts, disrupted flight conditions, prepared poorly and inattentively for flights, etc., more often than other subjects. Such interpretation of the pictures was observed much less often among first ($t = 2.41$; $P<0.02$), senior ($t = 3.29$; $P<0.001$) year cadets, let alone pilots ($t = 3.30$; $P<0.001$). The data are listed in Table 2.

The findings are consistent with the results of other studies using different methods [2, 7, 5]. This is indicative of the psychodiagnostic value of the data obtained using the TAT variant, which characterize the quality of discipline.

Discipline ratings obtained by the cadets in the TAT were submitted to correlation and factor analysis, with evaluation of discipline qualities furnished by their commanders and experienced pilot-methodologists in the course of conversation, results of practical flight training, achievement in theoretical education, general psychological screening evaluation and other parameters. The results of analysis are listed in Table 3.

Table 3. Correlation between discipline according to TAT and other parameters

Correlation parameter	Coefficient of correlation	P
Commanders' rating of discipline	0.35	<0.01
Discipline rating from conversation	0.28	<0.05
Achievement in practical flight training	0.42	<0.001
General rating of professional screening	0.34	<0.01
Achievement in theoretical studies	0.29	<0.05
Flight motivation according to TAT	0.35	<0.01

We found that for virtually all professionally important traits the discipline rating by the TAT had positive and reliable correlations. It should be noted that the correlation between discipline ratings of commanders in the course of observation and pilot-methodologists in conversations was less significant ($r = 0.25$; $P<0.05$) than between commander ratings and results of discipline evaluation by the TAT ($r = 0.35$; $P<0.01$).

Factor analysis confirmed the results of correlation analysis. One of the factors was called the factor of motivation and discipline demonstrated with the TAT. This factor also contained significant weights of achievement in flight training, general sthenia (according to TAT), attention, pedagogic evaluations in the course of special physical training and evaluation of discipline by commanders.

Thus, it can be assumed that the proposed modified TAT method can determine the attitude toward discipline of flying cadets within a relatively short period of time.

Analysis failed to demonstrate a significant correlation between the results of the Rosenzweig test and discipline ratings. For this reason, we decided to study how methodological parameters affect achievement in flight training, which has a positive correlation with cadet discipline ($r = 0.42$; $P<0.001$). We found that the intrapunitive orientation of cadets helps in their practical flight training achievement ($r = 0.36$; $P<0.01$).

Perhaps the subjects properly assessed their position and their mistakes with the intrapunitive type of reaction (it should be stressed that we are dealing with reactions of a normal personality, and for this reason the parameters did not exceed average values--20-30%). They resolved complicated situations on their own, did not enter into conflicts with pilot instructors and were more disciplined.

Some interesting results were obtained when we compared evaluations of general physical condition to extrapunitive and ego-defense type of reaction ($r = -0.25$; $P<0.05$). General indicators of health status, in turn, were correlated with achievement in flight training ($r = 0.31$; $P<0.01$).

It can be assumed that individuals with high extrapunitive parameters were more frustrated and in greater conflict. Individual analysis of marked extrapunitive

manifestations in subjects revealed that they coincided with instances of actual conflicts in everyday life, in the group with instructor pilots during practical training in flying techniques. They were characterized by a shortage of self-criticism, inability to find a rational solution to an existing situation. Obviously, such conflicts were not instrumental in good flight training.

The demonstrated link between extrapunitive type and tendency toward frustration coincides to some extent with the results of previously published studies [6].

Using factor analysis we found that parameters of extrapunitive orientation and ego-type of resolution of frustrations were minimal for the factor where achievement in practical flight training had the greatest weight. In this factor, evaluation of discipline and sociometric status had a significant weight. Conversely, in another factor, where the extrapunitive results were represented with the greatest weight, discipline rating had a weight with the opposite sign.

From the foregoing it can be assumed that a marked extrapunitive direction combined with the ego-defense type of resolution has an adverse effect on success of flight training, diminishes conformity of the personality, is instrumental in onset of conflict situations and elements of indiscipline.

In order to elicit significant psychodiagnostic information obtained by the Szondi test, the results of the method were submitted to correlation and factor analysis, with evaluation of cadet discipline and other parameters.

We found that there were low correlations between test results, discipline rating and other parameters. This is understandable, since the test was designed to detect mental deviations, and most subjects were in good health.

Individual analysis of the test profile revealed that strained and inadequate choices were typical of individuals who did poorly in flight and theoretical training, as well as cadets who tended to disrupt flight discipline. They most often selected photos of patients with epilepsy, hysteria and catatonia in the Szondi test.

Factor analysis established that one of the factors characterizing a normal, disciplined personality with high social status contained negative significant weights on the epilepsy, catatonia and sadism scales of Szondi's test and positive weights on the scale of conformism (homosexuality).

This confirmed our assumption that undisciplined personalities are characterized by a strained and inadequate choice. Such cadets most often selected photos of patients with a "greater pathological burden" (epilepsy, catatonia, hysteria).

Thus, it can be considered that the proposed projective methods permit demonstration of psychological traits that are of professional significance to cadets.

However, the greatest advantage of these tests is that discipline can be rapidly predicted. Of course, these characteristics are quite probabilistic, but they make it possible to give more attention to a given cadet, observe him while he works and define the prediction in the course of a conversation.

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UDC: 612.014.477-064:612.881

EFFECT OF BODY POSITION AND IMMOBILIZATION ON INTENSITY OF SPATIAL ILLUSIONS IN WEIGHTLESSNESS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 3 Feb 84) pp 23-26

[Article by F. A. Solodovnik and A. V. Chapayev]

[English abstract from source] Test subjects were exposed to short-term weightlessness in various positions: standing, seated, supine in the cosmonaut's chair and on the flat surface with the head kept straight ahead, bent forward or backward. Their susceptibility to illusionary sensations was measured. It was found that the development of spatial illusions in the weightless state was not correlated with body position, head position relative to the torso or restraint type.

[Text] Many Soviet and American cosmonauts reported that they developed spatial illusions during spaceflights. These illusions were mainfested primarily in the form of sensation of turning upside down, on the back or face down. Illusions appeared immediately after onset of weightlessness in the spacecraft [1, 6].

The nature of illusions in weightlessness had also been studied during aircraft flights over a parabolic curve [2-4]. It had been established that individuals who are experienced in flight work are less susceptible to spatial illusions in weightlessness [3, 4].

The methods in current use to prevent adverse conditions in cosmonauts in wieghtlessness do not permit adequate prevention of development of illusions pertaining to spatial position during spaceflights. At the same time, when performing operations to guide the craft in relation to a station or during various maneuvers in orbit, illusions could have an adverse effect on the quality of such work.

Illusions of spatial position were marked primarily when the cosmonauts sat in the regular seat of the descent vehicle of the spacecraft. Perhaps the fact that the cosmonaut is in a specific position, causing strain on some muscle groups and tightening of the seat-belt system are predisposing factors in weightlessness for manifestation of spatial position illusions. Moreover,

some cosmonauts reported that spatial position illusions appeared only when they tipped their head back, i.e., when it was in a specific position.

For this reason, investigation of the patterns of development of spatial position illusions in cosmonauts during spaceflights, as well as of the conditions that affect their intensity is a pressing problem of space medicine. The results of such studies could be used to refine steps to prevent this adverse state.

Our objective here was to investigate the effect of position of the body, positions of the head, as well as immobilization, on intensity of spatial illusions in weightlessness.

Methods

The studies were conducted during flights aboard a laboratory aircraft flying on a parabolic curve with production of brief weightlessness, with the subjects standing, seated in a chair without touching the back of the chair, supine in a mock-up of a spacecraft seat with legs raised close to the abdomen, while lying on a flat surface with elongated legs. The subjects held their heads in the following positions: "straight," tipped back at an angle of 30°, tipped forward at an angle of 30°. In one version with weightlessness, they performed exercises with the head in one position.

In the mock-up of a spacecraft seat, we conducted studies without immobilizing the subject (when he would soar slightly hardly touching the back of the seat) and with secure immobilization by strapping him in the seat.

Baseline studies were conducted during horizontal flight. The subject placed his head in the specified position and a Birtok instrument, which is designed to test spatial orientation, was brought up to his face and secured tightly [5]. The test was then repeated during brief weightlessness.

With onset of weightlessness, the subject closed his eyes for 5-10 s and tried to visualize his position in relation to the ceiling. He then opened his eyes and visually set the guiding device of the Birtok instrument using controls in accordance with his perception of top and bottom. The Birtok instrument ruled out the possibility of visualizing surrounding objects.

A total of 10 subjects familiar with brief weightlessness participated in the studies.

Results and Discussion

Illusions were demonstrated in 8 out of 10 subjects when changing to a state of weightlessness. In most cases they were manifested in the form of tilting the body backwards, and the impression was that the ceiling was in front, in the region of the lower body.

Under different testing conditions, some subjects had a distinct illusion as to their position in relation to "ceiling" and "floor," while others had a vague illusory sensation and had some difficulty in defining their position.

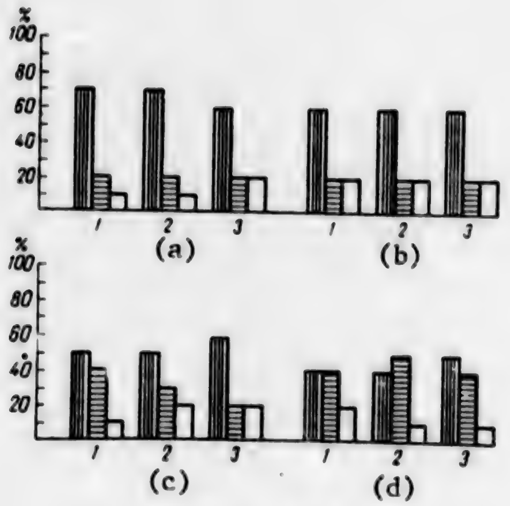

Figure 1.
Severity of illusions during brief weightlessness with the subject's body and head in different positions

A-d) seated, standing lying in mock-up of spacecraft seat, lying on flat surface

Here and in Figure 2: vertically striped bars--pronounced illusion of tilting backwards; horizontally striped bars--no illusions; white bars--ill-defined illusions

1) head erect
2) head tilted back
3) head bent forward

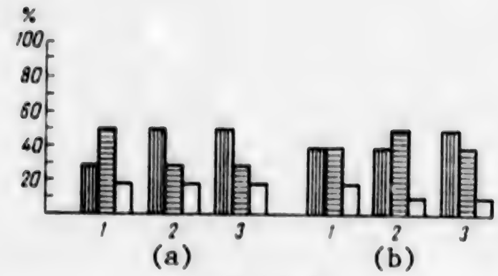

Figure 2.
Severity of illusions during brief weightlessness with subject lying in seat with (a) and without (b) immobilization

In sitting and standing positions, some subjects in weightlessness experienced only a minor deviation of the trunk to the back from the "floor-ceiling" vertical line. In others,the seeming angle of backward tilt of the body constituted 130-160° from the base position. In such cases the subjects felt that the "ceiling" is in the region of the lower half of the body and developed the sensation that they were "upside down." The number of subjects with marked illusions in seated position ("head erect") did not differ appreciably from the number who had them in standing position (Figure 1).

When lying down, there were somewhat fewer subjects with illusions than when standing and sitting. This could be related to individual reactions of some subjects or to occurring adaptation, since these studies were performed during 3, 4 and 5 flights.

In supine position, the angle of seeming backward tilt usually constituted 30-70°. Considering the fact that sitting and standing positions differed by 90° from supine position, it can be considered that the illusory deviations from the imaginary vertical plane in these positions were about the same. Consequently, it can be established that the severity of spatial illusions in weightlessness is unrelated to an individual's position.

The position of the subject's head in relation to the trunk had no significant effect on susceptibility to spatial illusions in weightlessness (see Figure 1). However, some subjects presented a change in magnitude of illusory deviation

or its disappearance with the head in certain position. Perhaps, tension of some cervical muscle groups could have some effect on extent of illusory sensations in some people. This occurred also among cosmonauts during spaceflights.

In supine position (on flat surface and in mock-up of spacecraft seat), the subjects experienced the illusion of the body tilted back together with the seat and flat surface, which assumed the same position as the subject in relation to the imaginary vertical. The subjects did not experience the sensation of the body shifting in relation to the supporting surface.

Immobilization in the seat (Figure 2) had no appreciable effect on the subjects' susceptibility to illusions. In all likelihood, the information from receptors of the skin, muscles and joints was not sufficiently significant to affect the severity of illusory sensations elicited by the effect of weightlessness on such receptor systems as the vestibular, interoceptive and proprioceptive.

In our opinion, the appearing illusions were closely related to the physical distinctions of stimulation of vestibular receptors, and they are a normal physiological reaction; for this reason, the illusory perceptions of spatial position in weightlessness should not be viewed as functional impairment of the vestibular analyzer, as believed by some researchers [7, 8].

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UDC: 612.13+612.17].014.47:612.76

TYPOLOGICAL CHARACTERISTICS OF HEMODYNAMIC STATES OF HEALTHY SUBJECTS IN ORTHOSTATIC POSITION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 25 Jul 83) pp 26-33

[Article by V. A. Dartsmeliya and G. S. Belkaniya]

[English abstract from source] Central circulation and respiratory function of 90 healthy men, aged 24-45, were investigated during active and passive tilt tests. It was found that circulation can be influenced by the orthostatic factor which is expressed as the stage of early effects, intermediate stage, and the stage of stabilized hemodynamics. With respect to cardiac output the three basic hemodynamic states can be distinguished: hypokinetic, intermediate and hyperkinetic. It is shown that circulation parameters in clino- and orthostatics are reciprocally related. It is demonstrated that the cardiorespiratory parameters used can be selectively employed in the classification of the circulating state in orthostatics. It is claimed that the hemodynamic conditions reflect the sequential phase states in circulation regulation. The concept of clino- and orthostatic normative characteristics of hemodynamics is presented.

[Text] There are many clinical studies of orthostatic changes in circulation. The traditionally demonstrated changes are evaluated as the cardiovascular system's reaction to an orthostatic factor, and for this reason a change from horizontal to vertical position is used as a test of functional state and reactivity of the cardiovascular system.

At the present time, interest in evaluating circulation in orthostatic position is growing. This is related primarily to the fact that the significance of orthostasis as the most constant physical condition of man's activities is becoming more and more apparent [3, 8, 12, 13]. Man spends two-thirds of his life in erect position; two-thirds of each day his functional state and regulation of circulation are governed by the influence of the gravity (hydrostatic) factor. This circumstance determines the significance of orthostatic position in the typical stationary hemodynamic state, rather than reactive. For this reason, when assessing baseline characteristics of circulation, one should be governed by vertical, rather than horizontal, position. The former must be taken as the basic physiological norm of hemodynamics in

an erect walking being such as man [1, 10, 15]. In actuality, man has two basic characteristics of the functional state of his two main systems--orthostatic and clinostatic physiological norms.

It is expressly from these positions that a revision must be made of the existing data and investigation pursued of basic physiological systems of the body, and particularly the cardiovascular system in orthostatic position. It is important to analyze and define the extent of changes, demonstrate the basic typological distinctions of central and peripheral circulation in orthostatic position. This was the purpose of our investigation.

Methods

We studied central hemodynamics in 90 clinically healthy subjects 24 to 45 years of age in active (90 people) and passive (47) orthostatic position. In order to standardize conditions in the studies of active orthostatic position, the subject was moved from one position to another passively, on a turntable, after which he stood actively and independently on the footstand of the table. When testing passive orthostatic position the following day, the subject was immobilized on the turntable in a parachute suspension system and moved to vertical (90°) position [7].

During the tests we recorded the basic parameters of external respiration (by the spirographic method) and central hemodynamics by tetrapolar thoracic rheography [11]. For analysis, we used indicial (scaled to body surface) parameters of central hemodynamics (stroke index (SI, in $m\ell/m^2$), cardiac index (CI, in ℓ/m^2) and specific peripheral vascular resistance (SPR, in $dyne \cdot s \cdot cm^{-5}$). Systolic ($BP_s$, in mm Hg) and diastolic (BP_d, in mm Hg) arterial pressure was measured by the Korotkov method. Mean arterial pressure was calculated using the formula, $BP_m = BP_d + 0.42\ BP_{puls.}$. Heart rate (HR per min) was determined from the rheogram. We used the amplitude of the differential rheogram (A_{dif}, in $\Omega \cdot s^{-1}$) as parameter of myocardial contractile function.

External respiration function was assessed by minute oxygen uptake scaled to body surface (O_2U, in $m\ell/m^2$), respiration rate (RR per min), tidal volume (V_T, in $m\ell$) and minute volume (MV, in ℓ/min). We calculated oxygen pulse ($OP = O_2U/HR$) and arteriovenous difference parameter ($AVD = O_2U/CI$) as cardiorespiratory parameters.

The parameters were recorded under basal metabolic conditions with the subjects in horizontal position. For the next 20 min of exposure to orthostatic position the tested parameters were recorded in the 1st, 5th, 10th, 15th and 20th min. Hemodynamic changes were evaluated as percentage of parameters in clinostatic state, taken as 100%.

Results and Discussion

The dynamics of orthostatic changes demonstrated distinctly phasic changes in recorded parameters (Figure 1). The levels of the latter in the 1st and 5th min, in both active and passive orthostatic position, differed significantly

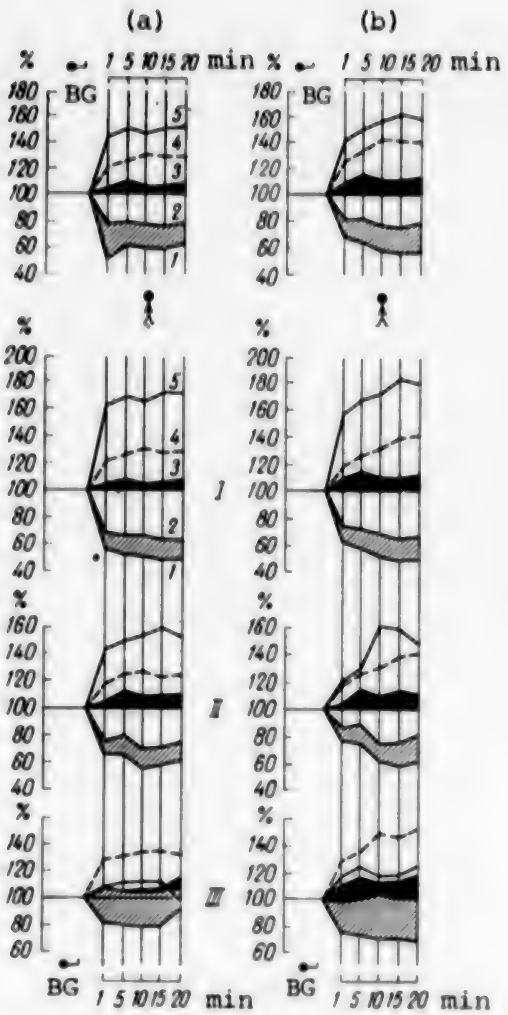

Figure 1.
Types of hemodynamic states in active (a) and passive (b) orthostatic tests

Top--general dynamics of stroke (1) and minute (2) cardiac output, BP_m (3), HR (4) and peripheral resistance (5). Below--the same with first, second and third hemodynamic types in orthostatic position. Baseline (BG) parameters in clinostatic position taken as 100%.

from subsequent time periods. As a rule, stabilization of hemodynamics was concluded by the 10th min. Evidently, the parameter levels in the first minutes reflected the intensity of the orthostatic factor, whereas the dynamics of the parameters from the 1st to 10th min were characterized by a process of triggering of mechanism for compensation of hemodynamic changes that occurred in the first minutes of orthostatic testing.

In the 10th-20th min, the parameters reflected stabilization of mechanisms of regulating the cardiovascular system in orthostatic position. In view of the foregoing, it was justified to measure the parameters in question only after the 10th min of the orthostatic test--this enabled us to assess the most adequately the period of stabilized hemodynamics. Our data indicate that the most informative evaluation of orthostatic changes in circulation can be made only by dynamic recording of the parameters in question. From the data referable to the first minutes after the subjects change to vertical position one can evaluate the extent of manifestation of the hydrostatic (gravitational) effect of the orthostatic test; up to the 10th min, the lability of transient processes and from the 10th to 20th min, the level of stable compensation of hemodynamic changes in orthostatic position. In this regard, we used the averaged parameters for the 1st-5th and 10th-20th min periods to characterize orthostatic circulation.

Although, as indicated by the data in Table 1, changes in BP_m level in the 10th-20th min of the orthostatic test fluctuated over the absolute range of 96 to 122%, we should mention that pressure dropped in only 4 out of the 90 cases and did not change in 6, i.e., the basic characteristic was elevation of BP_m. This characteristic was even more clearly demonstrable in the BP_d, which exceeded in all cases the level in clinostatic position. In orthostatic position we observed a 1 to 35% increment of HR in all cases. BP_s changes were more heterogeneous: it was below the clinostatic level in 35% of the cases,

above the latter in 49% and remained unchanged in the remaining 16% of the cases. There was an insignificant range of changes in BP_s: from 7% decline to 17% elevation.

The changes we observed in mean SI (40% decline), CI (22% decline) and SPR (50% increase) conformed to data obtained previously [3-5, 10, 12, 13, 17].

However, it should be noted that expressly these basic parameters of central hemodynamics changed in different directions and over the widest range in relation to their levels in clinostatic position. This was the most distinctly manifested with regard to CI, which changed in the absolute range of 60% decline to 54% increase, as compared to the clinostatic norm. These changes in CI were due to change in stroke cardiac output over the absolute range of 64% decrease to 8% increase, i.e., in most cases there was a decline of SI.

Even the mean decline of stroke cardiac output (40%), not to mention the extreme values for this decline that reached 64%, is indicative of rather appreciable hemodynamic changes in orthostatic position. And, if we consider that this situation persists and could become more intense over the entire period that man spends in vertical position (standing, walking, sitting), it becomes understandable that orthostatic position is a rather substantial disturbing condition for hemodynamics and requires constant tonic tension of nervous and humoral mechanisms of pressor regulation of the cardiovascular system. This interpretation of the physiological significance of orthostasis is indicative of the quite important role of the gravity factor to circulation in man as a being that walks erect.

In the literature there are descriptions of attempts at classifying reactions of the cardiovascular system to orthostatic factors. In most such studies, changes in BP and HR levels were taken as the basis for classification, including tolerance of the factor itself [9, 16]. For this reason, the known classifications include both standard and pathological states, i.e., they are mixed and consequently do not clearly reflect the substance of standard characteristics of circulation in orthostatic position. Use of changes in BP and HR as a classifier is inexpedient, primarily because these parameters change in the same direction and over a narrow range. This circumstance alone lowers drastically the limiting capacities of these parameters with regard to demonstration of qualitative typological differences and changes observed in orthostatic position. An even greater limitation is imposed by the fact that BP is the ultimate controllable and integral parameter, so that the mechanisms that maintain it (change in cardiac output, peripheral vascular resistance, etc.) are reflected quite arbitrarily in characteristics of BP level. At the same time, expressly these mechanisms determine the qualitative content of the distinctions of hemodynamic regulation and they are of definite clinical interest.

In this respect, the changes in cardiac output, which are demonstrable over a wide range and in different directions, reflect more objectively the heterogeneous hemodynamic mechanisms of maintaining mean BP in healthy subjects in orthostatic position. For this reason, evaluation was made of the direction of changes in cardiac output, in relation to the clinostatic state, in obtaining typological characteristics of the normal orthostatic state. This

Table 1. Comparative hemodynamic characteristics in active and passive orthostatic position in healthy subjects

Para-meters	Values	Active orthostatic position				Passive orthostatic position				Absolute range of fluctuation (% of baseline) for entire group and diff. (Δx)
		group	type I	type II	type III	group	type I	type II	type III	
SI	A	41,7±0,6	47,0±1,2	33,0±1,5	37,0±3,8	43,0±2,5	48,0±2,8	30,0±3,7	40,0±3,8	
	B	63,5±1,0	55,0±0,9	67,0±2,4	81,0±2,3	65,0±1,9	59,0±1,5	77,0±3,7	73,0±3,7	36—108 (72)
	C	60,0±0,8	49,0±0,7	59,0±1,2	84,0±2,4	55,4±1,9	49,0±1,3	61,0±2,7	68,0±3,0	
CI	A	2,8±0,08	3,1±0,06	2,2±0,07	2,4±0,2	2,7±0,13	3,1±0,22	2,0±0,13	2,4±0,3	
	B	79,0±1,4	64,0±0,9	80,0±2,6	105,0±3,2	81,0±2,7	73,0±1,5	88,0±3,4	100,0±4,9	40—154 (114)
	C	78,0±1,4	62,0±0,7	74,0±2,0	109,0±3,0	76,0±3,6	66,0±1,3	76,0±2,7	102,0±4,9	
SPR	A	3140±116	2545±53	3527±68	3999±86	3196±204	2551±179	4467±308	3795±563	
	B	148,0±2,8	174,0±3,3	142,0±4,2	110,0±3,6	147,0±3,9	164,0±4,8	126,0±4,6	122,0±5,5	66—269 (203)
	C	150,0±2,6	173,0±2,6	152,0±3,4	101,0±2,1	160,0±6,0	180,0±5,1	149,0±6,0	120,0±5,6	
A_{dif}	A	1,31±0,03	1,41±0,03	1,15±0,06	1,24±0,06	1,24±0,04	1,3±0,07	1,07±0,03	1,23±0,1	
	B	95,2±2,5	88,5±2,3	97,0±6,0	109,0±5,1	93,5±3,5	90,0±3,9	102,0±5,8	97,0±6,0	46—191 (145)
	C	100,6±2,7	93,5±2,3	104,0±6,0	114,0±6,0	92,8±3,4	89,0±4,2	94,0±5,9	102,0±9,1	
HR	A	66,0±0,8	68,0±1,0	66,0±1,6	64,0±1,5	63,5±1,1	65,0±1,3	62,0±5,7	61,0±1,7	100—169 (69)
	B	125,0±1,3	124,0±1,0	122,0±1,5	130,0±2,6	129,0±4,0	130,0±1,5	122,0±2,7	133,0±3,1	
	C	129,0±1,1	129,0±0,9	125,0±0,9	134,0±1,6	142,0±2,9	140,0±1,9	137,0±3,0	150,0±2,4	
BP_m	A	96,8±0,4	97,0±0,8	95,0±1,1	98,0±1,2	95,0±0,7	94,0±1,2	98,0±1,9	96,0±2,5	
	B	108,0±0,4	107,0±0,4	109,0±0,9	109,0±0,7	112,0±0,9	112,0±1,3	110,0±2,0	114,0±1,9	96—122 (26)
	C	107,0±0,4	105,0±0,3	109,0±0,8	106,0±0,5	111,0±1,0	110,0±1,0	111,0±1,7	114,0±1,1	
BP_s	A	120,8±0,7	122,0±1,2	118,0±1,8	120,0±1,3	117,0±1,3	118,0±2,1	116,0±2,6	116,0±2,6	
	B	103,0±0,4	103,0±0,5	105,0±1,1	105,0±0,7	107,0±1,0	106,0±0,8	105,0±1,5	110,0±2,4	91—117 (24)
	C	102,0±0,4	101,0±0,5	104,0±0,8	101,0±0,6	105,0±1,2	103,0±0,8	108,0±2,2	109,0±1,7	
BP_d	A	79,3±0,4	79,0±0,9	78,0±1,3	82,0±1,2	78,4±0,6	77,0±0,8	80,0±2,1	81,0±1,9	
	B	113,0±0,5	111,0±0,6	115,0±0,9	114,0±1,0	117,5±1,3	117,0±1,4	116,0±2,9	120,0±2,8	99—135 (36)
	C	113,0±0,6	112,0±0,4	115,0±0,9	112,0±0,7	118,0±1,0	118,0±1,0	116,0±2,0	121,0±1,7	

Key for this and Table 2:
A) absolute values of parameters in clinostatic position
B, C) mean parameters in 1st-5th and 10th-20th min, respectively, of orthostatic position, as percentage of clinostatic position taken as 100%

approach enabled us to single out 3 main hemodynamic types or states of circulation in orthostatic position (see Table 1): I (61% of the cases), II (21%) and III (18%).

The two extreme types are hypokinetic (I) with marked decline of SI (by 51%) and CI (by 36%) and hyperkinetic (III) with average of 9% increase in CI. In addition, there is the intermediate or mixed type (II) of circulation in orthostatic position. All of these types differ reliably ($P<0.001$) in mean stroke and cardiac output. The dynamic characteristics of changes in the parameters studied conform to the general features described above (see Figure 1) during the orthostatic tests with all three types.

Individual typological circulatory distinctions in orthostatic position are rather stable, and for this reason they are reproduced in repeated tests and persist in passive orthostatic position (see Figure 1). If the hypokinetic or hyperkinetic type is demonstrable in active orthostatic position, it is also usually reproduced in the passive test. As for the intermediate or mixed type, unlike its characteristics in active orthostatic position, they were close to the hyperkinetic type in the passive test. It is important to stress that the hemodynamic characteristics of the clinostatic resting state did not differ on different test days, as can be seen from the data listed in Table 1. This indicates, in the first place, that the functional state of the cardiovascular system is identical during the tests, as well as appropriateness and adequacy of the methods used for evaluation and analysis of hemodynamic parameters.

The two extreme hemodynamic types in orthostatic position (hypokinetic and hyperkinetic) do not differ reliably ($P>0.05$) in BP_m and, what is particularly important, in HR increment. Against this background, there is distinct manifestation of qualitative difference in mechanisms of maintaining BP in orthostatic position. The most marked decline of SI and CI is observed with the hypokinetic type; it is compensated in the 1st-5th and 10th-20th min, respectively, by the most marked increase in SPR--by 74 and 73%, respectively. This warrants the conclusion that BP_m level with this type is maintained by a peripheral vascular mechanism.

With the hyperkinetic type, efficient regulation of orthostatic changes in hemodynamics is effected by a cardiac mechanism. This is manifested by an increase in rate of cardiac output (amplitude of differential rheogram increases by 14%). Intensification of inotropic myocardial function is reflected by reliably less marked ($P<0.001$) decrease in stroke output, which is the cause of 9% increase of CI in orthostatic position with this type.

As for the mixed (III) type, it differs reliably from types I and III in characteristics of cardiac output. There is an intermediate type of change in peripheral vascular resistance, coming close to the characteristics of a hypokinetic state.

We should call attention to the substantial difference between clinostatic parameters of individuals with different hemodynamic types in orthostatic position (see Table 1). The reliably higher CI ($P<0.001$) and lower SPR ($P<0.001$) in horizontal position correspond to the hypokinetic type in

orthostatic position. Clinostatic hemodynamics with types II and III are characterized by considerably greater peripheral vascular resistance and lower minute volume. While clinostatic hemodynamic parameters are consistent with the conventional norm with type I, they were largely similar with types II and III to the characteristics of the early stage of development of a hypertensive state [14]. It should be noted that all subjects with types II and III hemodynamics in orthostatic position the BP in clinostatic position corresponded to a clinically normal range, and there was no information about elevation of this parameter in their history. On this basis, we interpret the mixed and hyperkinetic hemodynamic types in orthostatic position as a possible transient hyperreactive state in development of arterial hypertension. It was possible to detect the "hyperreactor" group on the basis of the approach we used--combined clinostatic and orthostatic evaluation of hemodynamics--and it is of clinical importance.

The impression is gained that the orthostatic hemodynamic types we distinguished reflect successive phases of regulation of circulation in the direction of increasing peripheral vascular resistance (Figure 2). The general direction of compensation of the orthostatic factor is optimization of hemodynamics, which is manifested by decreased reaction (according to decline of SI and CI in the first few minutes) and formation of a hyperkinetic response at the phase of stable regulation (10th-20th min). This is possible, provided there is gradual strengthening of systemic increase in peripheral vascular resistance, which persists in clinostatic position and is distinctly demonstrable in the hyperreactive group. To put it graphically, this is the price of optimization of regulation of hemodynamics in orthostatic position, which is the most constant condition of man's activities and function of his cardiovascular system.

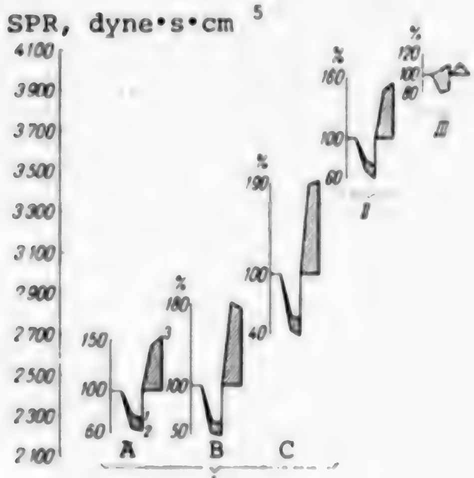

Figure 2.
Characteristics of reaction to orthostatic factor of circulation according to SI (1) and CI (2) and vascular reaction according to SPR (3) with types I, II and III hemodynamic states in active orthostatic position

Hemodynamic parameters in clinostatic position are taken as 100%. Characteristics of hemodynamic types are graphically situated in accordance with absolute SPR in clinostatic position

The consistency of successive change in manifestation of orthostatic decline of cardiac output against a background of progressive increase in peripheral vascular resistance in clinostatic position at rest is also demonstrable in differential analysis of the group of subjects with type I hemodynamic state in orthostatic position. This group was the most representative in the sample we studied 55 people out of 90). Using sigma integration, this entire group was divided into 3 subgroups: in subgroup A cardiac output in orthostatic position exceeded $+1\sigma$ of the mean for type I, subgroup B corresponded to the $\pm1\sigma$ range and subgroup C was less than -1σ. Figure 2 shows that establishment of systemic increase

in peripheral vascular resistance in clinostatic position of hyperreactive subjects (types II and III hemodynamic state in orthostatic position) precedes progressive manifestation of the orthostatic factor (greater decline of SI and CI) and corresponding increase in vascular reactivity (increase of SPR) within the range of functional characteristics of hemodynamic state type I. The latter is apparently the initial factor in the gradual and progressive increase of vascular tonus, which prevents manifestation of the gravity factor in hemodynamics. The decrease in capacity of the vascular system due to systemic increase in vascular tonus leads to compensatory decline of minute circulation volume, which is rather distinctly demonstrable in the hyperreactive subjects in resting clinostatic position (see Table 1).

The hemodynamic states (three types) singled out in both active and passive orthostatic position are virtually the same in functional parameters of external respiration (Table 2). Changes in the latter were mainly in the same direction, and they were characterized by moderate increase in O_2U and MV. The same direction of changes had also been noted in other investigations [2, 6], which is indicative of the deciding significance of hemodynamic changes in typological distinctions of the body's functional state in orthostatic position.

A more distinct difference in orthostatic hemodynamic states was demonstrable by the integrated O_2U/CI parameter, whereas these differences were not demonstrable with the O_2U/HR parameter (oxygen pulse) that is used quite extensively. Sensitivity of O_2U/CI and its differentiating capacity when the changes in O_2U are in the same direction are attributable to the qualitatively different hemodynamic features with the different types of orthostatic states. In fact, O_2U/CI reflects the arteriovenous difference for O_2. In orthostatic position it increases, reflecting activation of mechanisms of utilizing oxygen. It is the most marked with hypokinetic type of hemodynamics in orthostatic position. This can be interpreted as triggering of a tissular mechanism of compensation for the decline in circulation volume. In a hyperkinetic state, in the presence of increazed circulation volume, this mechanism is expressed to a significantly lesser degree, which is also indicative of optimization of hemodynamic regulation in orthostatic position with the hyperkinetic type of circulation.

Table 2. External respiration in the main hemodynamic states in active and passive orthostatic position of healthy subjects

Parameter	Values	Active orthostatic position				Passive orthostatic position			
		entire group	type I	type II	type III	entire group	type I	type II	type III
O_2U	A	162.0±8.0	164.0±6.0	158.0±13.0	162.0±10.0	162.0±8.0	162.0±6.0	154.0±15.0	166.0±6.0
	B	124.0±2.0	123.0±3.0	126.0±11.0	125.0±18.0	123.0±2.0	127.0±4.0	127.0+7.0	118.0±4.0
	C	119.0±3.0	120.0±4.0	116.0±12.0	121.0±9.0	118.0±3.0	119.0±4.0	120.0±2.0	116.0±3.0
V_T	A	894.0±39.0	925.0±[illegible]0.0	751.0±58.0	953.0±66.0	783.0±53.0	731.0±55.0	707.0±86.0	918.0±78.0
	B	96.0±2.0	95.0±3.0	101.0±3.0	93.0±2.8	107.0±2.0	108.0±3.5	104.0±5.0	107.0±3.2
	C	96.0±3.0	96.0±4.0	92.0±3.0	101.0±4.0	109.0±2.0	112.0±3.0	113.0±7.0	97.0±12.0
RR	A	13.3±1.0	12.9±0.4	14.0±1.4	13.6±0.8	14.5±1.0	14.2±0.7	16.3±1.8	14.3±1.1
	B	109.0±2.0	109.0±2.6	109.0±5.1	107.0±4.3	105.0±2.0	106.0±1.8	101.0±5.7	104.0±5.5
	C	114.0±2.0	116.0±3.0	115.0±3.5	109.0±5.1	109.9±2.0	108.0±2.1	111.0±2.5	109.0±6.5
MV	A	11.9±0.8	11.9±1.0	10.5±0.4	12.9±1.8	12.5±0.5	12.1±1.0	14.6±0.5	12.0±1.5
	B	105.0±2.0	104.0±3.5	99.0±4.4	111.0±4.4	111.0±2.0	114.0±3.0	111.0±3.7	104.0±4.6
	C	110.0±2.0	111.0±4.0	110.0±6.5	106.0±5.0	119.0±2.0	120.0±2.2	105.0±7.8	126.0±7.8
AVD	A	6.6±0.3	5.8±0.3	7.4±0.7	7.7±0.9	6.6±0.3	5.8±0.4	8.7±0.7	7.3±0.7
	B	179.0±5.0	197.0±6.7	178.0±5.0	139.0±6.0	159.0±6.0	179.0±4.6	134.0±9.0	123.0±8.5
	C	179.0±6.0	193.0±9.6	187.0±7.0	125.0±4.6	175.0±5.0	196.0±6.9	167.0±3.0	125.0±8.8
OP	A	—	2.6±0.7	2.5±0.1	2.6±0.2	—	2.7±0.7	2.8±0.1	2.9±0.7
	B	—	103.0±3.5	104.0±3.0	109.0±6.0	—	99.6±4.9	96.0±3.0	87.4±3.7
	C	—	97.0±4.1	100.0±3.4	102.0±8.8		88.0±4.0	96.0±7.3	78.0±2.9

The results of analysis indicate that there are differences in hemodynamics in clinostatic and orthostatic position. There are some reciprocal relations between these positions. The hypokinetic hemodynamic state in orthostatic position corresponds to hyperkinetic or eukinetic circulatory features in clinostatic positions, whereas with the mixed and hyperkinetic orthostatic types of circulation the clinostatic state presents a markedly hypokinetic nature.

The reciprocal relations between clinostatic and orthostatic standard characteristics of circulation can also determine qualitative differences in reactivity of the cardiovascular system in these states to diverse factors (physical loads, psychoemotional tension, pharmacological factors, etc.). Special mention should be made of the fact that the qualitative hemodynamic differences in orthostatic position (hypokinetic, mixed or intermediate and hyperkinetic types) can alter significantly reactivity of the cardiovascular system of man who walks erect, as well as mental and physical activity which occurs primarily in orthostatic position and is largely determined by circulatory status.

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UDC: 616.36-008.839.3-02:612.766.2]-07

INVESTIGATION OF SPECTRUM OF HUMAN BILE ACIDS DURING 120-DAY ANTIORTHOSTATIC HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 15 Jul 83) pp 33-35

[Article by O. V. Zhiznevskaya and I. L. Medkova]

[English abstract from source] The composition of bile acids in the B and C portions of the duodenal juice of six essentially healthy test subjects exposed to 120-day head-down bed rest was investigated. As the exposure continued, the percentage content of bile acids conjugated with taurine increased and that of bile acids conjugated with glycine decreased. The rapid and significant decrease of the ratio of glycine conjugated to taurine conjugated bile acids suggests a specific modification of the synthetic function of hepatocytes under the above conditions.

[Text] Previous studies revealed that a number of changes occurs in the bile-producing function of the liver during hypokinesia [3, 5]. However, there have been few such studies, and they were pursued primarily in experiments on animals (rats) [3, 5]. It is known that the bile-secreting process in rats has several physiological distinctions (absence of gallbladder, prevalence of cholic acid conjugated with taurine in the spectrum of bile acids), which makes it difficult to extrapolate findings to man. For this reason, it was interesting to examine the bile acid spectrum of man during long-term hypokinesia.

Methods

A total of 6 essentially healthy subjects 30 to 40 years of age were submitted to the study; they spent 120 days on strict bedrest in antiorthostatic position (head end tilted at an angle of -4.5°). Duodenal catheterization was performed on the 20th, 67th, 89th and 112th days of hypokinesia and 10th day of the recovery period using the conventional method. The spectrum of bile acids was identified in B and C portions of duodenal juice by means of chromatography in a fine layer on Silufol plates [1]. Bile acids were extracted with ethanol (95°) in a proportion of 1:10. Bile acids were separated in a system of isobutyl acetate, glacial acetic acid and water in a ratio of 10:8:5. Spots were demonstrable after spraying 10% alcohol solution of phosphomolybdic acid on the plates. Quantitative assay of bile acids was made using densitometry in reflected light on a Carl Zeiss instrument in the presence of standards.

Percentages of bile acids in B and C portions of duodenal contents during 120-day antiorthostatic hypokinesia

Bile acid	Statist. parameter	Background		Day of hypokinesia: 20		67		89		112		Recovery period (10th day)	
		B	C	B	C	B	C	B	C	B	C	B	C
TCA	$M \pm m$	22.0±2.2	19.6±2.42	30.0±5.44	33.1±5.81	24.95±3.7	18.3±0.94	28.9±4.1	47.9±9.04	29.7±2.6	31.2±5.4	31.2±5.2	20.2±2.4
	n	6	6	6	3	4	4	5	5	3	3	4	5
	p			>0.1	>0.05	>0.05	>0.5	>0.1	<0.02	>0.05	>0.05	>0.1	>0.5
TDCA and CTDCA	$M \pm m$	10.6±1.6	12.1±3.48	18.9±3.19	25.3±6.3	12.6±2.7	18.1±4.2	16.1±2.8	14.8±2.9	18.0±3.8	23.3±8.6	26.7±7.0	30.9±5.6
	n	6	4	6	4	4	5	5	5	3	3	4	5
	p			<0.05	>0.1	>0.5	>0.2	>0.1	>0.5	>0.1	>0.2	>0.05	<0.02
GCA	$M \pm m$	24.7±1.3	23.2±2.63	20.0±1.7	23.95±1.9	22.9±4.1	18.8±2.6	23.02±4.0	17.97±3.85	22.5±3.7	19.3±4.4	15.7±3.8	22.2±1.7
	n	6	6	6	4	4	5	5	5	3	3	4	5
	p			<0.05	>0.5	>0.5	>0.2	>0.5	>0.2	>0.5	>0.2	>0.05	>0.5
GDCA and CGDCA	$M \pm m$	42.7±2.46	43.4±4.11	31.2±2.75	25.9±2.23	39.7±4.2	32.7±6.1	32.0±4.8	19.4±4.4	29.7±2.6	26.3±3.8	26.5±2.6	26.8±4.2
	n	6	6	6	4	4	5	5	5	3	3	4	5
	p			<0.02	<0.01	>0.5	>0.1	>0.05	<0.01	<0.01	<0.02	<0.01	<0.02
GA/TA	$M \pm m$	2.2±0.29	2.12±0.26	1.12±0.18	1.0±0.12	1.73±0.23	1.18±0.36	1.4±0.33	0.68±0.18	1.13±0.14	0.83±0.12	0.75±0.12	1.02±0.18
	n	6	6	6	4	4	4	5	5	3	3	4	5
	p			<0.01	<0.01	>0.2	>0.05	>0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Results and Discussion

On the 20th day of hypokinesia there was increase in percentage of taurocholic acid (TCA) in portions B and C of duodenal contents, but these changes were not reliable (see Table). On the 67th day there was an insignificant increase in TCA content of portion B and drastic increase in portion C (to 48% versus 19.5% as the baseline; $P<0.02$). On the 112th day, TCA content of portion B differed little from the status at the preceding assay, whereas a decline in TCA level of bile was demonstrated in portion C, although it was substantially higher than the background values. On the 10th day of the recovery period TCA content of portion C reverted to the base level and remained high in portion B ($P>0.1$).

On the 20th day of bedrest there was approximately 2-fold increase in percentage of taurodeoxycholic (TDCA) and chenotaurodeoxycholic (CTDCA) acids in portions B and C of duodenal contents, and this increase was reliable in portion B.

By the 67th day of the study, there was decline in percentage of TDCA and CTDCA, as compared to the 20th day of hypokinesia, but these parameters were above background levels. The 112th day of hypokinesia was again characterized by a tendency toward increase in percentage of TDCA and CTDCA in bile. On the 10th day of the recovery period there was significant rise of the tested parameters in both portions of bile, as compared to background values.

On the 20th day of the study, we demonstrated a reliable decline in percentage of glycocholic acid (GCA) in portion B of duodenal contents. It retained its base level in portion C. GCA content remained low in both bladder and renal bile on the 67th,

89th and 112th days of hypokinesia. On the 10th day of the recovery period GCA content of portion B remained low, as compared to background values and in portion C it reverted to the base level.

On the 20th day of bedrest we also demonstrated a reliable decline in percentage of glycodeoxycholic acid (GDCA) and chenoglycodeoxycholic acid (CGDCA) in both portions of duodenal contents.

On the 67th day the levels of these acids rose somewhat, as compared to preceding stages (particularly in portion C), but remained below background values. On the 112th day of the study, there was further decline in percentage of these acids in both bile portions, as compared to the background period. These changes were reliable.

As a result of the increase in percentage of bile acids conjugated with glycine, there was decline of glycoconjugate ratio (GA/TA) starting on the 20th day of the study. This finding was the most reliable toward the end of the hypokinetic period and in the recovery period (background 2.20 in bladder bile and 2.12 in liver bile; on 89th day of the study 0.68 in liver bile; $P<0.01$; on the 10th day of the recovery period 0.75 in bladder bile; $P<0.01$).

According to data in the literature, in normal human bile there is prevalence of glycine conjugates of bile acids, exceeding by 2-6 times the levels of taurine compounds [2]. The drastic and reliable decline of glycoconjugate-tauroconjugate coefficient demonstrated in our studies is indicative of some alteration in synthetic activity of liver cells. In order to determine the nature of this change and possible sequelae, it is necessary to conduct further investigations to characterize exocrine function of the liver under hypokinetic conditions, not only according to parameters of bile acid spectrum, but composition of bile lipids, which give us an idea about the colloid stability of bile acid salts in solution, i.e., lithogenicity of bile.

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UDC: 612.13.014.477.014.49

VASCULAR MECHANISMS OF ADAPTATION TO ANTIORTHOSTATIC POSITION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 29 Sep 83) pp 35-39

[Article by T. A. Kabesheva, S. V. Kopanev, N. Ye. Panferova and A. F. Zavadovskiy]

[English abstract from source] Using occlusion plethysmography and rheography, the state of peripheral circulation of 18 test subjects during 25 exposures to head-down tilt was investigated. The test subjects were subdivided into two groups: nine subjects actively changed their body position by 90° and nine others were passively transferred to the head-down position at an angle of -12°. It was found that regular training facilitated the development of vascular mechanisms which assisted adaptation to the head-down tilt: it decreased the tone of resistance vessels of the arms and legs and that of capacitance vessels of the legs; it increased the tone of cerebral resistance and capacitance vessels. The tone of leg capacitance vessels varied, depending on the type of training: passive tilting increased their compliance and active tilting decreased it. The final result of the tone redistribution in the peripheral vascular bed during training was a smaller increase of head blood content and a smaller fluid outflow from the legs.

[Text] Antiorthostatic hypokinesia (AOH) is considered to be the most adequate model simulating the effects of weightlessness on the circulatory system [6, 10, 12]. AOH conditioning enhances the body's resistance to redistribution of blood in a cranial direction [1, 9]. The role of the vascular system in human adaptation to AOH has not been sufficiently studied, and the significance of repeated conditioning has been virtually uninvestigated. It is quite important to study the mechanisms of vascular adaptation to AOH from both the practical point of view for development of means of preventing the adverse effects of weightlessness on man and from the theoretical aspect to determine the role of the vascular system in man's adaptation to weightlessness.

Our objective here was to investigate compensatory vascular reactions to repeated antiorthostatic factors.

Methods

This study was conducted on 18 essentially healthy men who were divided into 2 groups (9 in each). The 1st group of subjects was submitted to -12° AOH on a turntable 3 times a week for 2 h at a time, for 2 months (passive AOH; 25 times); the 2d group was conditioned for AOH conditions for the same periods of time (total of 25 training sessions), actively changing the position of their body and assuming a head down position at an angle of 90° (active AOH). In both groups, prior to using AOH, we assessed in horizontal position the status of the vascular system of the lower leg and forearm before, after 10 and 25 training sessions, as well as 20 days after completing the cycle of conditioning only in the 1st group of subjects. We used occlusion plethysmography. To occlude the veins of the arm and thigh, we pumped air into cuffs secured in the arm and thigh region to a pressure of 50 mm Hg in 1-2 s. Plethysmogram changes in the first 5 s after occlusion were interpreted as the indicator of volumetric flow rate (in mℓ/100 g tissue/1 min), reflecting arteriolar tonus [2, 5, 11]. After pressure in the cuffs was lowered and the plethysmogram returned to its base level, we performed stepped occlusion, raising pressure in the cuffs to 30 mm Hg then, without dropping pressure, to 50 mm Hg. Preliminary occlusion of veins using pressure of 30 mm Hg provided for a stable level of filling of veins and, upon subsequent increase in pressure to 50 mm Hg, the difference in increment of limb volume with change in pressure from 30 to 50 mm Hg served as the indicator of extensibility of capacitive vessels (in mℓ/100 g tissue) [2, 3]. In addition, in the training sessions with active AOH before training, after 10 and 25 sessions we examined filling of orbital tissues by plethysmography with occlusion of cervical veins using a pressure of 20 mm Hg [4]. To assess the dynamics of adaptation to AOH conditions before and after 25 training sessions we used a 2-h functional test tilting the head end of the turntable down at an angle of 12° (AOH 12°) for the 1st group of subjects and a 20-min AOH 30° test for those in the 2d group.

When performing the functional AOH 12° test, we measured hourly the parameter of volumetric blood flow rate and increment in leg and arm volume with occlusion of leg and thigh veins; we also measured hourly the perimeters of the lower leg and arm every 3 cm to calculate volumes and characteristics of values for fluid redistribution in AOH position. In the AOH 30° test, we determined total and pulsed filling of the brain and lower leg. On rheograms of the head we calculated the dicrotic index (DCI), which reflects the dynamics of arteriolar tone in the region studied, diastolic index (DSI), which reflects the dynamics of veinous tone, parameter of tone of large and medium caliber arteries (α/T). Ophthalmodynamometry was used to study hemodynamics in the region of the retina.

Results and Discussion

Our findings revealed that the volumetric blood flow rate in the regions of the upper and lower extremities of subjects in horizontal position changed in the same direction, namely, it increased during training with active and passive antiorthostatic position (Figure 1). Training with active AOH elicited significant increase in volumetric flow rate in the leg region--this parameter increased by a mean of 2.3±0.16 mℓ/100 g tissue/min or by 53%, holding at this level after 25 training sessions. Crural volumetric blood flow rate when

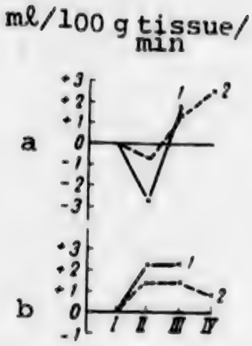

Figure 1.
Changes in parameter of volumetric blood flow rate in region of forearm (a) and lower leg (b) in subjects in horizontal position after conditioning with active (1) and passive (2) AOH, as compared to pretraining data. Here and in Figures 2 and 3:
  I) before training
 II) after 10 training sessions
III) after 25 " "
 IV) 20 days after training
  x) reliable changes as compared to pretraining parameter ($P<0.05$)

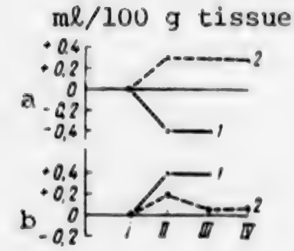

Figure 2.
Changes in increment of volume of arm (a) and leg (b) with staggered occlusion of veins of arm and thigh after training with active (1) and passive (2) AOH with subjects in horizontal position

training with passive AOH increased by 1.4±0.09 mℓ/100 g tissue/min, or 34%, after 10 training sessions, and remaining at that level for the duration of subsequent training. Volumetric blood flow rate in the crural region remained an average of 21% higher [than baseline] 20 days after completion of training with passive AOH.

Volumetric blood flow rate in the region of the forearm when training with active AOH changed in two phases: it decreased by 2.7±0.26 mℓ/100 g tissue/min, or 27%, after 10 training sessions (see Figure 1), then increased after 25 sessions, exceeding the base values by 1.8±0.2 mℓ/100 g tissue/min, or 18%. When training with passive AOH, there was decline after 10 sessions in volumetric blood flow rate in the forearm region by 0.7±0.26 mℓ/100 g tissue/min, or 12%, followed by elevation after 25 sessions to levels exceeding the baseline by 1.45±0.18 mℓ/100 g tissue/min, or 25%. During the 20 days of the recovery period after training with passive AOH, volumetric blood flow rate in the arm region remained higher by 2.6±0.2 mℓ/100 g tissue/min, or 52%.

Training with active antiorthostatic position elicited a reliable 0.4±0.1 mℓ/100 g tissue increase in increment of crural volume after both 10 and 25 training sessions (Figure 2). The parameter of maximum increment of crural volume increased somewhat when subjects were tested in horizontal position with occlusion of femoral veins during training with passive antiorthostatic position, but the changes were unreliable ($P>0.05$, see Figure 2).

The changes in increment of forearm volume with occlusion of arm veins depended on the nature of training: training with active AOH lowered the increment with occlusion of arm veins to the same extent, i.e., by 0.4±0.09 mℓ/100 g tissue, or 33%. Training with passive AOH, on the contrary, raised this parameter by 0.3±0.5 mℓ/100 g tissue, or 37%, after both 10 and 25 training sessions (see Figure 2).

Studies of the vascular bed of the brain in the orbital region with occlusion of cervical veins in the 2d group of subjects revealed a decline in volumetric blood flow rate by an average of 0.9±0.14 mℓ/min, or 27%, after 10 and 25 training sessions. At the same time, increment in tissue volume in the orbital region with occlusion of cervical veins decreased by 2.3±0.65 and 3.2±0.7 mm^3, or 27 and 38%, after 10 and 25 training sessions, respectively (Figure 3).

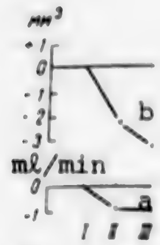

Figure 3.
Parameters of occlusion orbital plethysmogram of subjects in horizontal position after training with active antiorthostatic position
a) volumetric blood flow rate
b) increment in tissue volume with occlusion of cervical veins

Studies using the functional AOH 12° test revealed that, before training, the change from horizontal position under AOH conditions was associated with a decline of volumetirc blood flow rate in the region of the lower leg and forearm (Figure 4) by an average of 1.2±0.14 and 1.1±0.17 mℓ/100 g tissue/min, or 27 and 19%, respectively. After 25 training sessions with passive antiorthostatic position the change to AOH position did not elicit significant changes in volumetric blood flow rate in the vessels of the lower leg, and it remained at the same level as in horizontal position. Volumetric blood flow rate in the region of the forearm increased by 50% with change to AOH after training, as compared to the parameter in horizontal position.

AOH 12° for 2 h before training was associated with increase in maximum increment of crural volume (extensibility of capacitive vessels) with femoral occlusion from 1.9±0.19 to 2.7±0.16 mℓ/100 g tissue, as compared to data in horizontal position; the reaction of the venous bed to the subjects' change to AOH did not change (see Figure 4). Training with passive antiorthostatic position had no appreciable effect on extensibility of the capacitive vascular system of the lower leg and caused some increase in

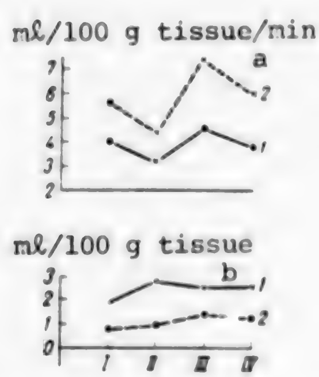

Figure 4.
Parameters of occlusion plethysmogram of lower leg (1) and forearm (2) during 2-h AOH 12° before and after training with passive antiorthostatic position
a) volumetric blood flow rate
b) increment in crural and arm volume with occlusion of brachial and femoral veins
I) before training with subjects in horizontal position
II) before training, after 2-h of AOH
III) after 25 trainings sessions with AOH 12°
IV) 12 days after training with AOH 12°
×) reliable changes as compared to pretraining data (P<0.05)

this parameter in the forearm region with AOH 12°. Measurement of lower leg and forearm perimeters during the 2 h of AOH revealed that before the training period, at the end of the 2d h in this position, efflux of fluid from the crural region constituted an average of 37±2.8 mℓ, versus 24±2.3 mℓ after training, i.e., it decreased by 35%. Redistribution of fluid to the region of the forearm with change from horizontal position to AOH was insignificant both before and after training.

Training with active AO [antiorthostatic position] also helped retain fluid in the region of the lower limbs in AOH position. Thus, the functional AOH 30° test revealed that total filling of the legs with blood during AOH diminished by 160±24 mℓ before training and by 107±25 mℓ after. Concurrently, according to rheographic data, after training there was considerably less increase in delivery of blood to the head with change from horizontal position to AOH. Before training, increment in filling of the head with blood during this test constituted 41±7.8 mℓ and after training it was 21±3.4 mℓ ($P<0.05$). Evidently, the diminished delivery of blood to the head in AOH position is attributable to significant increase in tone of arteries and veins of the vascular system of the head in the course of training. Indeed, before training, when changing from horizontal position to AOH the rheographic index increased by 0.085±0.008 Ω in the frontomastoid lead and by 0.042±0.005 Ω in the bimastoid lead. After training, there was considerably less rise of these indexes, namely by 0.028±0.003 and 0.017±0.002 Ω, respectively ($P<0.001$). After training, parameter α/T increased by 100%, DCI by 57% and DSI by 54%. After training, with change to AOH conditions the increment of diastolic pressure in the retinal artery also diminished and was half as marked (from 24±0.5 to 12±0.2 mm Hg) ($P<0.005$).

Consequently, vascular mechanisms play an active part in human adaptation to AOH. The change from horizontal position to AOH conditions is related to significant changes in hemodynamic conditions in the upper and lower halves of the body. Due to change in direction of hydrostatic pressure of blood there is decline of blood pressure in venous and arterial vessels of the lower limbs and elevation in those of the upper half of the body [7, 8]; influx of arterial blood decreases and efflux of venous blood from the lower limbs increases; concurrently, there is increase in influx of arterial blood and decrease in efflux of venous blood from the upper half of the body. During man's adaptation to repeated exposure to AOH there was change in the peripheral vascular bed of the lower and upper extremities, as well as the brain: tonus of resistive vessels of the lower leg diminished, and by the end of the training period tonus of resistive vessels of the forearm also decreased. Tonus of capacitive vessels changed in the same direction as tonus of resistive vessels: tonus of crural capacitive vessels diminished after training with passive and active AO, and tonus of capacitive vessels of the forearm diminished after training with passive AO. Tonus of resistive and capacitive vessels of the brain increased after training. Redistribution of vascular tone is an adaptive mechanism for providing the appropriate hemodynamic level in different parts of the body with AOH. The decrease in tonus of resistive vessels in the lower limbs diminishes resistance to blood flow in this part of the vascular bed and, consequently, provides for increased influx of blood into the arterial bed. The decrease in tone of capacitive vessels, in turn, diminishes efflux of blood and causes its retention in the venous system of the lower limbs. Apparently, the same mechanisms prevent redistribution of blood into the central bed and vessels of the

brain, in addition to improving delivery of blood to the lower limbs in AOH position, increasing filling of the legs. Studies under AOH conditions demonstrated the efficiency of these mechanisms in maintaining circulation. Influx of blood to the lower extremities with AOH after training was at virtually the base level observed in horizontal position; at the same time, there was increased fluid retention in the legs. Concurrently, there was a decrease in increment of filling of head vessels with blood and a drop of arterial pressure in retinal vessels. As conditioning to AOH progressed there was attenuation of objective and subjective signs of blood rushing to the head (slight edema of the face, erythema of the sclera and headache) in AOH position. Active conditioning for AOH was more effective. The nature of the conditioning exercises had a different effect on the capacitive bed of the upper limbs. In the case of training with passive AO, there was decrease in tonus of forearm vessels, which can be viewed as a mechanism that is instrumental in unloading the central bed in AOH position. Active conditioning did not elicit such an effect; on the contrary, after training with active AO, extensibility of the capacitive vascular bed of the forearm diminished. Apparently, in the latter case, the decreased extensibility of capacitive vessels is attributable to change in condition of muscle groups of the arms in head-down position. Thus, during conditioning for repeated AO there is development of vascular mechanisms which prevent a blood overload in the central bed and brain, on the one hand, and improve delivery of blood to the lower extremities in AOH position, on the other.

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UDC: 612.3+612.824].014.477-064

CEREBRAL HEMODYNAMICS AND VENTRICULAR FUNCTION IN -15° ANTIORTHOSTATIC POSITION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 24 Aug 83) pp 39-42

[Article by V. I. Sokolov]

[English abstract from source] Sixteen men were exposed to head-down tilt at -15° for 6 h. Cerebral circulation was examined by bipolar rheoencephalography, ventricular function by one-dimensional echoventriculometry, and blood pressure by Korotkoff's sounds. Group 1 consisting of 10 test subjects tolerated the antiorthostatic exposure well enough (they reported only blood rush to the head and moderate facial puffiness). They showed stable parameters of cerebral circulation, ventricle size, and mean blood pressure, which is indicative of adequate compensatory capabilities of their organisms. Group 2 consisting of 6 test subjects exhibited polymorphic clinical symptoms, including the syndrome of liquor hypertension (burst-like headache, autonomic dysfunction, etc.). This was accompanied by decreased pulse pressure of cerebral vessels, primarily in the vertebrobasilar area, instability of the vessel tone against the background of marked dilatation of the capacitance vessels and brain ventricles.

[Text] Absence of hydrostatic pressure of body fluids, which leads to their redistribution in a cranial direction [1], is one of the pathogenetic mechanisms of effects of weightlessness on man.

The increased influx of blood and spinal fluid to the head elicits substantial changes in the system of cerebral circulation, which are manifested primarily by change in venous blood content in the skull [7].

The magnitude of cerebral blood flow is determined not only by the amount of blood delivered into the skull and vascular tonus, but to a large extent by cerebrospinal fluid pressure in the ventricular system of the brain [2]. For this reason a combined approach is required to the study of changes in hemodynamics and ventricular system of the brain when simulating body fluid redistribution in a cranial direction by means of antiorthostatic [head-down tilt] position (AOP).

Methods

This study involved the participation of 16 men 27 to 34 years old who spent 6 h in AP at an angle of -15°.

Cerebral hemodynamics were examined by rheoencephalography [6] in the right frontomastoid and bimastoid leads, which reflect the dynamics of pulsed delivery of blood and vascular tone in the basin of the internal carotid artery and vertebrobasilar zone, respectively. The REG was recorded using a Galileo (Italy) 8-channel electroencephalograph and 4RG-1A bipolar rheograph. We calculated the following parameters: rheographic index (RI), which reflects pulsed delivery of blood to cerebral vessels, indicator of tonus of large vessels of the head (α/T), dicrotic (DCI) and diastolic (DSI) indexes, which reflect the dynamics of arteriolar and venular tonus, respectively, in the regions examined [5].

We examined the reactions of the ventricular system of the brain using one-dimensional echoventriculometry, with calculation of index of the third ventricle (Dv_1) and index of the medial wall of the lateral ventricle (Pm_1). The method has been described previosly [4].

Arterial pressure was measured by the Korotkov method, with calculation of mean dynamic pressure using the formula of Hickham [3].

The results were processed by the variation statistical method using Student's criterion. Differences between findings were considered reliable with $P<0.05$.

Results and Discussion

During the test with AOP -15° on 10 subjects (1st group), we found that there was good tolerance, as manifested clinically by moderate puffiness of the face and sensation of blood rushing to the head. Six subjects (2d group) presented polymorphism of symptoms, i.e., along with marked rush of blood to the head, puffiness and cyanosis of the face, there was autonomic dysfunction (acrohyperhidrosis, cooling of distal parts of the arms and legs).

Such clinical symptoms were associated with marked hemodynamic changes in the cerebral circulatory system. Thus, pulsed delivery of blood to the reservoir of the internal carotid artery increased more in subjects of the 2d group than the 1st, by 106.6 and 29.6%, respectively, as compared to the base level (Figure 1). The 2d group of subjects presented a 50.3% decline of RI in the vertebrobasilar zone. Such redistribution of pulsed filling between vascular regions is an important compensatory mechanism to maintain adequate cerebral blood flow.

With respect to the vascular system of the brain, we demonstrated compensatory dilation of arterioles in the 1st group of subjects, in both the frontomastoid and bimastoid leads (Figure 2) in addition to moderate dilatation of cerebral veins and venules (Figure 3). DCI decreased by 9.3 and 8.2%, respectively. The changes in indicator of tonus of large-caliber vessels (α/T) were not reliable.

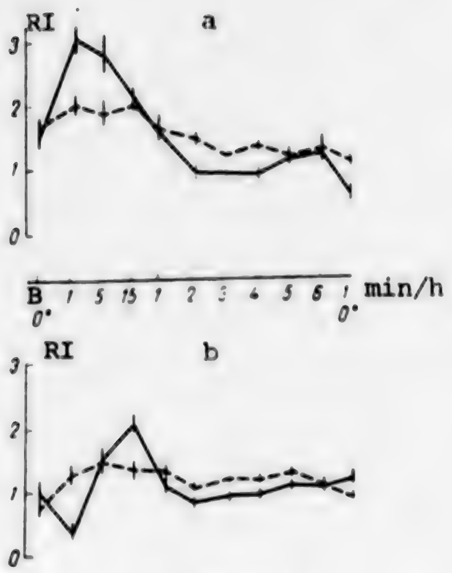

Figure 1.
Dynamics of RI in AOP at angle of -15°
Here and in Figures 2-4:
a) frontomastoid lead
b) bimastoid lead
B) background
Dash line--1st group of subjects
Boldface line--2d group of subjects

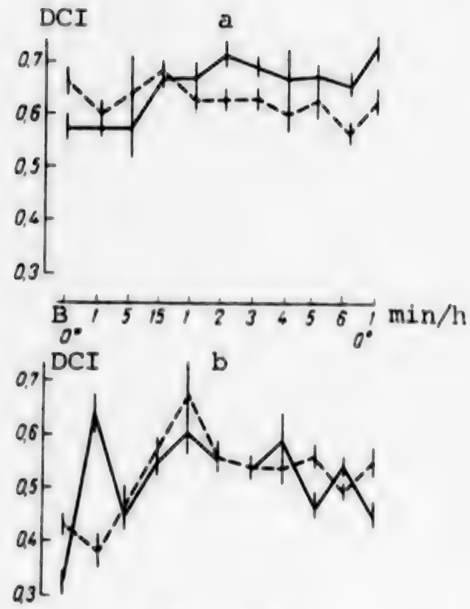

Figure 2.
DCI dynamics in AOP (-15°)

In the 1st group of subjects, stabilization of pulsed filling in the basin of internal carotid occurred by the end of the 1st h of AOP, whereas in the vertebrobasilar region RI was 52% above the base level throughout the period in AOP. Concurrently, there was stabilization of vascular tonus (arterioles and venules) in the frontomastoid lead, whereas in the bimastoid lead a decline of pulsed delivery of blood to cerebral vessels was manifested against the background of compensatory reactive constriction of small and medium caliber vessels, reaching peak values by the end of the 1st h of AOP (DCI increased by 63%, as compared to base level). These changes in hemodynamic parameters of the brain were observed in the presence of improved venous efflux from the cranial cavity, as manifested by decreased puffiness and cyanosis of the face in the 1st group of subjects, as well as 46.5% increase in DSI by the 15th min in AOP, as compared to base value. Concurrently, we demonstrated stable dimensions of the ventricular system of the brain, which confirmed good compensatory qualities of the system of spinal fluid circulation in the 1st group of subjects (Figure 4).

We observed brief Dv_1* only in the 1st min of AOP by 62%, as compared to base level, which was indicative of elevation of spinal fluid pressure in the 3d ventricle due to its hydrodynamic migration in a cranial direction when changing to a position with the "head lower than the legs." There was compensatory elevation of mean dynamic pressure (by 12.6%, as compared to base level), which is an important compensatory mechanism to maintain constant perfusion pressure of cerebral tissue [8].

In the 2d group of subjects, a splitting headache, microphotopsia appeared and intensification of autonomic dysfunction by the 15th min of AOP. The most

*Translator's note: Word obviously omitted--decrease or increase--in source.

marked clinical manifestation was dilatation of the ventricular system of the brain--decline of Dv_i and elevation of Pm_i to 12.6 arbitrary units. This was indicative of development of the clinically circumscribed syndrome of spinal fluid hypertension in subjects of the 2d group.

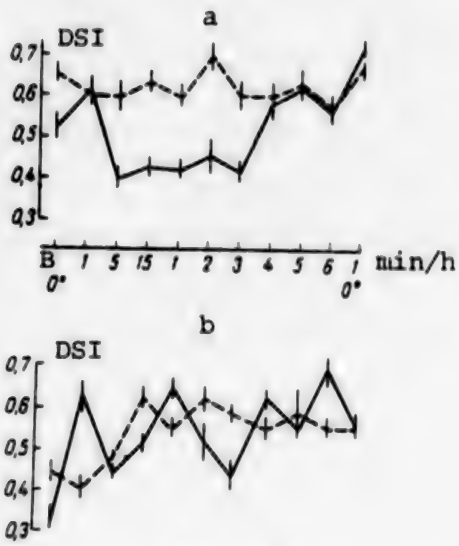

Figure 3.
DSI dynamics in AOP (-15°)

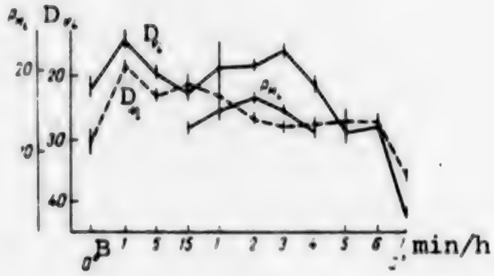

Figure 4.
Dv_i and Pm_i dynamics in AOP (-15°)

Elevation of spinal fluid pressure in cerebral ventricles leads to decline of pulsed delivery of blood and cerebral blood flow in both the system of the internal carotid arteries and the vertebrobasilar zone, which could be associated with development of signs of circulatory hypoxia. RI decreased by 34.4% in the frontomastoid region and 9.3% in the bimastoid, as compared to base levels. The decrease in pulsed delivery of blood was associated with development of a marked hypertensive reaction of arterioles in both the system of the internal carotid and vertebrobasilar zone (DCI increased by 24.1 and 103.2%, respectively).

Individuals in the 2d group were characterized by unstable vascular tonus, particularly in the vertebrobasilar region of blood supply, which is indicative of deficiency of their vascular regulatory mechanism. Concurrently, we observed marked dilatation of capacitive vessels in the frontomastoid lead and unstable tonus of veins and venules in the bimastoid lead.

There was no reliable change in blood pressure of subjects in the 2d group.

By the end of the 4th-5th h of AOP they presented normalization of dimensions of the ventricular system of the brain against the background of elevation of DSI in vascular regions. This is indicative of improved venous efflux from the cranial cavity, as a result of which there was disappearance of clinical manifestations of intracranial hypertension and relative stabilization of the basic hemodynamic parameters of the brain and systemic arterial pressure.

Thus, in AOP at an angle of -15°, we demonstrated changes in the system of cerebral hemodynamics and ventricular system, manifested in a number of subjects by development of the syndrome of spinal fluid hypertension against the background of redistribution of body fluids in a cranial direction, and this must be borne in mind when working on problems of professional expertise.

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UDC: 612.766.2-08:]612.173.3-612.22

EFFECT OF SHORT-TERM ANTIORTHOSTATIC HYPOKINESIA ON DYNAMICS OF CARDIORESPIRATORY PARAMETERS DURING GRADED PHYSICAL EXERCISE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 4 Aug 83) pp 43-46

[Article by A. M. Genin, V. M. Baranov, V. G. Shabel'nikov, N. M. Asyamolova, A. N. Kotov, M. Yu. Volkov, K. S. Yurova and A. T. Poleshchuk]

[English abstract from source] Seven healthy volunteers were exposed to head-down tilt at -15° for 5 h. Before and after exposure they exercised on a bicycle ergometer in the supine and seated positions. During the study their respiration function, gas exchange and arterialized blood parameters were measured. It was found that after exposure the physical aerobic performance diminished. The changes detected suggest that a lower exercise tolerance can be caused not only by a decreased circulating blood volume but also by increased energy expenditures of the cardiorespiratory system itself.

[Text] It is known that operators' physical work capacity diminishes after exposure to simulated weightlessness [2, 5, 6, 8]. However, it is still unclear which of three conjugate mechanisms (bioenergetics of muscles, transport of respiratory gases in blood or pulmonary ventilation) limits tolerance to physical loads (PL).

Our objective here was to determine the role of changes in exchange of gases and circulation in human reactions to PL following brief (i.e., not yet eliciting dystrophic changes in muscles) exposure to simulated weightlessness.

Methods

We tested 7 healthy men 27-30 years of age, weighing 70-88 kg, who exercised on an Ergotest bicycle ergometer on a graded WL program in background studies supine and seated, as well as in seated position after 5-h exposure to antiorthostatic hypokinesia (AOH) with a tilt angle of -15°. PL steps constituted 10, 30, 10 and 60% of nominal PWC_{170} [1, 9]. Mean nominal PWC_{170} for the group was 3.73 W/kg. Increase in heart rate (HR) in excess of 170 min^{-1} served as an indication to discontinue the tests.

Physical work capacity was evaluated according to maximum HR and maximum oxygen uptake at the last PL step, as well as actual PWC_{170} [1, 3, 9]. Changes in ventilation, gas exchange and HR were monitored continuously using an automated set of equipment of the Yaeger firm equipped with a computer, for examination of the cardiorespiratory system. Analysis of blood gases and acid-base status was made using a model ABL-2 gas analyzer of the Radiometer firm; arterial pressure was taken by the Korotkov method. In all we conducted 14 studies. The results were averaged for the group; we determined mean error and reliability of changes according to the sign criterion.

Results and Discussion

Tolerance to PL varied at different stages of the tests. Before AOH, the assigned PL program was completed by all subjects; after 5-h AOH, they stopped pedaling prematurely in 8 cases out of 14.

Table 1. Dynamics of physical work capacity parameters with change in position and after 5-h AOH

Stage of study	HR, min^{-1}				Actual PWC_{170} W/kg	O debt, (STPD), ℓ	Total V_{O_2} during PL, (STPD), ℓ
	resting	10% of nominal PWC_{170}	30% of nominal PWC_{170}	60% of nomin. PWC_{170}			
BEFORE AOH, SUPINE	76.5±3.8	94.1±4.4	113.6±2.9	160.7±3.6	2.62±0.14	2.96±0.23	9.82±0.22 B
BEFORE AOH; SITTING	80.6±5.3	92.9±5.4	109.2±5.3	161.0±4.1	2.58±0.12	2.21±0.50	9.07±0.77
AFTER AOH, SITTING	84.0±4.2	101.5±4.7*	125.6±5.2*	166.2±4.5	2.41±0.11	2.25±0.26	9.32±0.50

*Statistically reliable changes caused by AOH ($P<0.05$).

As can be seen in Table 1, some differences were observed between HR values in supine and seated position only at rest and they disappeared with light exercise. AOH led to increase in pulse rate at all levels of exercise. Maximum HR increment, as compared to the baseline, was observed with moderate level of exercise. As a result, all subjects presented changes in the same direction in actual PWC_{170}/kg body weight (see Table 1). The values were minimal when exercising in seated position after AOH and maximal during exercise in seated position before AOH. At the same time, overall O_2 uptake and oxygen debt showed virtually no difference during maximum exercise under the three different conditions.

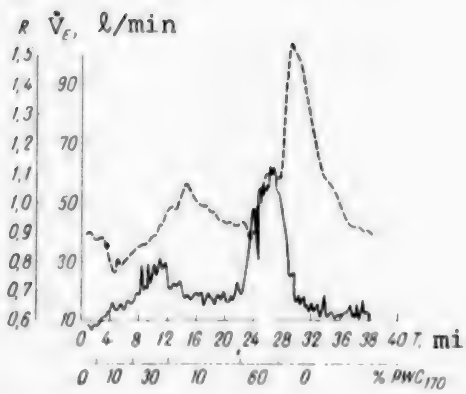
Since HR increase is the only mechanism for increasing circulation volume (CV) [1, 4], it can be assumed that the pulse increase observed during exercise after AOH is aimed at holding the required MV at a given rate of oxygen uptake (V_{O_2}). And, in spite of the decline after AOH of PWC_{170}, which characterizes maximum physical work capacity, V_{O_2} level at maximum exercise remained unchanged. This enables us to conclude that the cardiorespiratory changes due to AOH did not lead to diminished delivery of oxygen to muscles and did not limit the intensity of aerobic energetic processes.

The increase in oxygen capacity of blood due to concentration was also involved in maintaining the required V_{O_2}. AOH led to increase in concentration of

hemoglobin in all subjects. Average decline constituted 0.4 g%, which corresponded to about 3% decline in circulating blood volume (Table 2). There should have been a corresponding increase in oxygen capacity and viscosity of blood [3, 6, 9]. There was increase by an analogous value in concentration of hemoglobin during exercise before AOH (see Table 2). It is known that this effect is attributable to more intensive filtration of fluid in functioning muscles from capillaries into tissues, and it could lead to decline of stroke volume of the heart at maximum exercise, limiting its tolerance [1, 5, 6]. However, this effect was noticeably attenuated by AOH, and for this reason we cannot attribute diminished work capacity to it.

Table 2. Changes in parameters of gas exchange during exercise in different positions and after 5-h AOH (-15°)

Parameter	Resting			Exercise 60%, PWC_{170}		
	before AOH, supine	before AOH seated	after AOH seated	before AOH supine	before AOH seated	after AOH seated
$\dot{V}_E$, ℓ/min	6.24±0.60	7.35±1.62	7.37±0.83	58.0±2.4	52.7±2.1	52.0±1.1
V_T, ℓ	0.58±0.05	0.65±0.07	0.74±0.06	2.80±0.38	2.42±0.91	2.60±0.12
$\dot{V}O_2/\dot{V}_E$	38.5±3.4	35.3±7.8	40.7±7.1	39.1±2.3	41.8±2.8	42.6±1.3
R	0.89±0.04	0.88±0.03	0.86±0.02	1.08±0.01	1.11±0.03	1.12±0.03
$\dot{V}_A$, ℓ/min	4.38±0.42	4.67±0.45	5.39±0.68	49.2±3.4	48.6±2.6	50.9±2.0
V_{Df}, ℓ	0.17±0.08	0.24±0.14	0.20±0.15	0.39±0.30	0.19±0.2	0.05±0.10
p_aCO_2, mm Hg	41.4±0.7	42.5±0.9	41.6±0.5	41.9±0.9	42.1±0.9	41.3±0.1
p_aO_2, mm Hg	69.8±2.1	65.9±1.5	70.9±1.7	77.3±2.7	82.3±2.	76.3±2.4
pH	7.398±0.006	7.392±0.007	7.398±0.003	7.351±0.006	7.341±0.006	7.352±0.004
BE, meq/ℓ	+0.4±0.7	0.5±0.3	0.5±0.2	−2.6±0.5	−3.2±0.2	−3.2±0.4
Hb, g%	15.5±0.2	15.7±0.2	16.1±0.2	15.9±0.2	16.1±0.2	16.3±0.3



Dynamics of minute ventilation volume ($\dot{V}_E$) and respiratory quotient (R) during graded exercise in subject V. Boldface line—$\dot{V}_E$, dash line—R. Values at different phases of exercise (% of nominal PWC_{170}) are given under the x-axis.

A physical load constituting 60% of nominal PWC_{170} exceeded the anaerobic threshold, as indicated by excessive CO_2 output, which caused significant rise of respiratory quotient, to 1.08-1.12 during exercise and to 1.4-1.6 in the first minutes of the recovery period (see Figure). Blood oxidation by the products of anaerobic processes during exercise led to reliable decline of pH and standard bicarbonates (BE), which apparently elicited elevation of p_aCO_2, as compared to resting value, as a result of the Bohr effect (see Table 2). There was virtually no difference in values of p_aCO_2 during the period of maximum physical load and at rest. However, it is logical to assume that it would be expedient to lower p_aCO_2 to preserve homeostasis when blood is oxidized during strenuous exercise, thereby retaining an adequate blood pH by increasing minute volume of pulmonary ventilation ($\dot{V}_E$).

As can be seen in Table 2, $\dot{V}_E$ increased during exercise proportionately to $\dot{V}_{O_2}$, as indicated by the stable coefficient of oxygen uptake (CUO_2) when changing from the resting state to maximum exericse before and after AOH. And, judging by the values for V_{Df} (see Table 2), the efficiency of pulmonary ventilation was somewhat lower during exercise in supine position than in seated position, which required a larger volume. These findings are consistent with the subjective evaluation of exercise in supine position as being the most strenuous.

The increase in $\dot{V}_E$ occurred mainly due to increase in tidal volume (V_T), which reached a mean of 50.6% of vital lung capacity (VLC) in supine position and 43.8-45.9% of VLC in seated position, before and after AOH, respectively. These respiratory volumes have been demonstrated in well-conditioned athletes during maximum exercise [4, 7]. However, respiratory rate, which increased with performance of maximum exercise to 20-22/min^{-1}, remained almost half the value in our studies than in well-trained athletes with an analogous heart rate [4, 7]. Hence, maximum velocity of air flow during exercise by this group of subjects was considerably slower than obtained by athletes. This may be indicative of considerably greater nonelastic resistance to breathing, and it warrants the assumption that the subjects' respiratory system was unable to provide a volume of pulmonary ventilation adequate to the physical load.

Indeed, using the Siggaard-Andersen nomogram, one can become convinced of the fact that p_aCO_2 had to drop to 33.5-34 mm Hg to maintain a constant background pH level during maximum exercise. According to the equations for pulmonary exchange of gases, the p_aCO_2 drop required for stable pH could be obtained with an unchanged circulation volume and the same metabolic rate as a result of increase in alveolar ventilation ($\dot{V}_A$) to 61-63 ℓ/min, which is considerably higher than the values we observed (see Table 2).

However, AOH had virtually no effect on extent of blood oxidation, $\dot{V}_A$ and p_aCO_2 during exercise. Hence, the inconsistency between pulmonary ventilation and intensity of anaerobic processes after AOH did not become more marked. Nor was their a change in rate of delivery to blood of products of anaerobic processes and, accordingly, contribution of these processes to energy expended by functioning muscles.

Thus, the changes in the cardiorespiratory system elicited by 5-h AOH -15° did not limit the intensity of aerobic processes and did not lead to its decline. The observed decline of physical work capacity after AOH was apparently related to the fact that the energy of these processes was used in the body, from the standpoint of less efficient performance of exogenous work. Since brief AOH could hardly influence the efficiency of mechanoenergetic processes in muscle cells, it can be assumed that the cause of poorer tolerance to exercise after AOH was the increased oxygen uptake by respiratory muscles (due to increased nonelastic resistance to respiration) and myocardium due to increase in blood viscosity. This hypothesis is consistent with the results of studies of mechanics of respiration.

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UDC: 612.766.2-08:612.398.192.014.477.014.44

INVESTIGATION OF SOME ASPECTS OF AMINO ACID METABOLISM IN MAN DURING BRIEF EXPOSURE TO ANTIORTHOSTATIC HYPOKINESIA COMBINED WITH ULTRAVIOLET RADIATION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 7 Jul 83) pp 46-49

[Article by A. S. Ushakov, T. F. Vlasova, Ye. B. Miroshnikova, N. Ye. Panferova and T. P. Murugova]

[English abstract from source] Changes in the amino acid pool in the plasma of test subjects exposed to short-term head-down tilt combined with ultraviolet irradiation were investigated. Exposure to head-down tilt alone (group 1 of 3 test subjects) and combined with ultraviolet irradiation (10 sessions) (groups 2 and 3 of 3 test subjects each) acted as a stress agent that diminished the amino acid pool. Exposure to 2-hour head-down tilt in combination with 20 UV irradiations (groups 2 and 3) increased the amino acid pool as a result of inhibition of anabolic and stimulation of catabolic processes. The amino acid pool did not return to normal within the recovery period allowed.

[Text] The results of investigations of hypokinesia revealed that it affects amino acid metabolism in man [1-4, 6]. In particular, there is depression of protein synthesis in tissues in the presence of the hypokinetic syndrome; the intensity of such synthesis is largely determined by concentrations of free amino acids in cells [7]. Investigation of the free amino acid pool of blood is of some interest, since the latter are metabolically related to tissue amino acids. This permits indirect evaluation of the intensity of biochemical processes in tissues. We failed to find any data in the literature concerning the effect of combined exposure to hypokinesia and ultraviolet radiation (UVR) on amino acid metabolism in man.

We assayed here the levels of free amino acids in human blood plasma during combined exposure to 2-h antiorthostatic [head-down tilt] hypokinesia (-12°; AOH) and UVR.

Methods

Determination of levels of plasma free amino acids was made using ion-exchange chromatography with a Liquimat III (Labotron, FRG) automatic analyzer [5, 9]. At first, the plasma specimens were deproteinized with crystalline sulfosalicylic

Plasma levels (mg%) of free amino acids

Amino acid	Baseline period (n=9)	1st group (control) test period (n=6)	1st group (control) recovery (n=6)	2d group 10 UVR (n=3)	2d group 20 UVR (n=3)	2d group recovery (n=3)	3d group 10 UVR (n=3)	3d group 20 UVR (n=3)	3d group recovery (n=3)
ISOLEUCINE	0.58 ± 0.05	0.49 ± 0.02	1.01 ± 0.06*	0.41 ± 0.03*	1.21 ± 0.39	1.32 ± 0.12*	0.52 ± 0.08	1.31 ± 0.22*	1.20 ± 0.22*
LEUCINE	1.48 ± 0.11	1.08 ± 0.06*	2.06 ± 0.42	0.93 ± 0.08*	1.66 ± 0.26	2.07 ± 0.07*	1.05 ± 0.05*	2.18 ± 0.19*	2.42 ± 0.18*
VALINE	2.15 ± 0.15	1.90 ± 0.10	2.12 ± 0.18	1.31 ± 0.17	1.84 ± 0.22	2.27 ± 0.10	1.50 ± 0.30	2.63 ± 0.44	2.79 ± 0.01*
THREONINE	2.75 ± 0.12	2.48 ± 0.22	1.31 ± 0.33*	3.73 ± 0.30*	3.69 ± 0.75	2.36 ± 0.16	3.99 ± 0.49*	1.77 ± 0.27*	1.83 ± 0.15*
SERINE	0.47 ± 0.04	0.42 ± 0.03	0.53 ± 0.04	0.37 ± 0.03	0.64 ± 0.10	0.61 ± 0.14	0.32 ± 0.04	0.64 ± 0.08	0.71 ± 0.13
METHIONINE	1.00 ± 0.05	0.81 ± 0.08	1.31 ± 0.20	0.64 ± 0.03*	1.78 ± 0.32*	1.22 ± 0.23	0.79 ± 0.20	1.80 ± 0.35*	1.29 ± 0.17
TYROSINE	1.34 ± 0.09	1.02 ± 0.06*	1.18 ± 0.33	0.95 ± 0.08*	1.26 ± 0.15	1.11 ± 0.13	0.89 ± 0.17*	1.46 ± 0.26	1.16 ± 0.15
PHENYLALANINE	1.27 ± 0.14	0.90 ± 0.08*	0.74 ± 0.12*	0.59 ± 0.11*	0.92 ± 0.26	0.89 ± 0.13	0.71 ± 0.16*	0.71 ± 0.08*	0.86 ± 0.06
CYSTINE	0.58 ± 0.06	0.31 ± 0.07*	0.52 ± 0.04	0.34 ± 0.03*	0.93 ± 0.20	0.58 ± 0.03	0.35 ± 0.04*	0.88 ± 0.05*	0.77 ± 0.10*
ASPARTIC ACID	1.82 ± 0.20	1.21 ± 0.06*	1.61 ± 0.01	1.77 ± 0.16	2.64 ± 0.42	1.40 ± 0.24	0.83 ± 0.16*	1.72 ± 0.25	1.81 ± 0.21
GLUTAMIC ACID	1.92 ± 0.21	1.66 ± 0.02	1.54 ± 0.23	1.43 ± 0.08*	1.72 ± 0.44	2.11 ± 0.61	1.27 ± 0.28	1.72 ± 0.32	1.81 ± 0.21
PROLINE	1.95 ± 0.14	1.26 ± 0.10*	1.19 ± 0.16*	1.40 ± 0.22	1.70 ± 0.35	1.59 ± 0.17	1.06 ± 0.36*	1.24 ± 0.25*	1.93 ± 0.22
GLYCINE	2.25 ± 0.17*	1.76 ± 0.06*	2.57 ± 0.30	1.54 ± 0.10*	2.30 ± 0.33	3.04 ± 0.45	1.71 ± 0.13*	2.29 ± 0.04	2.71 ± 0.46*
ALANINE	2.58 ± 0.30	2.23 ± 0.30	3.33 ± 0.40	2.49 ± 0.10	5.08 ± 0.15*	2.53 ± 0.20	2.94 ± 0.38	6.38 ± 0.77*	3.09 ± 0.30
LYSINE	1.72 ± 0.15	1.44 ± 0.12	1.56 ± 0.08	1.05 ± 0.13*	1.21 ± 0.08*	1.70 ± 0.20	1.15 ± 0.26	1.96 ± 0.38	1.97 ± 0.23
HISTIDINE	1.28 ± 0.19	1.46 ± 0.23	1.80 ± 0.42	0.55 ± 0.01*	1.29 ± 0.06	2.18 ± 0.08*	0.59 ± 0.06*	2.49 ± 0.36*	2.73 ± 0.18*
ARGININE									
TOTALS	25.1	20.4	24.4	19.5	29.9	27.0	19.7	31.2	28.5

*P<0.05, as compared to baseline period.

acid [8]. Three groups of subjects participated in this study: the 1st group consisted of 6 subjects who spent 2 h under AOH conditions (-12°) at the time that the 2d and 3d groups (3 people in each) were exposed to specific doses of UVR (three-quarters and 3 biodoses, respectively). UVR was delivered from a mixed source at wavelengths of 280-400 nm in addition to 2-h AOH (-12°). Venous blood was drawn on fasting subjects in all groups twice, after the 10th and 20th exposure. In the recovery period, blood was drawn on the 13th day of the study. The results obtained in the course of testing plasma free amino acid levels are listed in the Table.

Results and Discussion

In the first group of subjects, total free amino acid content of plasma decreased to 20.4 mg%, as compared to the base period (25.1 mg%). The reliable decline of amino acid pool occurred due to decrease in leucine, phenylalanine, cystine, aspartic and glutamic acids, glycine and alanine, i.e., 7 of the 17th amino acids studied. Such decrease in blood amino acid concentrations is inherent in short-term hypokinetic conditions [1, 4, 6].

On the 13th day of the recovery period, leucine, phenylalanine, alanine, aspartic and glutamic acid levels reached the baseline, while cystine and glycine levels dropped even more. Against this background, there was increase in concentration of isoleucine (P<0.001) and decrease in threonine content (P<0.01) (see Table).

Thus, 2-h AOH elicits changes inherent in early stages of hypokinesia (up to the 12th day) [2]. It is expressly in this period that hypokinesia acts as a stress stimulus with typical reaction that slows down biosynthetic processes [7] leading to increased selective utilization of free amino acids of blood, which ultimately leads to reduction of the amino acid pool.

In the 2d group of subjects (UVR, 3/4 biodose, combined with 2-h AOH), after 10 doses of radiation there was a decline of amino acid pool to 19.5 mg%, as compared to baseline (25.1 mg%), and no differences as compared to parameters for the 1st group of subjects. The reliable ($P<0.02-0.001$) decline occurred as a result of decrease in concentrations of isoleucine, leucine, valine, tyrosine, phenylalanine, cystine, aspartic acid, alanine, histidine and arginine. There was unreliable decrease in concentrations of proline, glycine and methionine with concurrent increase in threonine ($P<0.02$). Lysine and glutamic acid content did not change.

After 20 doses of radiation (3/4 biodose UVR combined with 2-h AOH), on the contrary, there was an increase to 29.9 mg% in amino acid pool (baseline 25.1 mg%), and 20.4 mg% in the 1st group of subjects. There was reliable increase in concentration of lysine and tyrosine, and decline of histidine level.

Thus, after exposure to radiation 20 times, the subjects in the 2d group showed changes in amino acid balance inherent in long-term (over 12 days) AOH [3] (see Table).

Definitive normalization of parameters of amino acid metabolism had not occurred on the 13th day of the recovery period, in particular, there was further reliable rise in levels of isoleucine, leucine and arginine, and unreliable decline of cystine content. Total amino acids constituted 27 mg% (versus 25.1 mg% initially).

It must be noted that comparative analysis within groups according to UVR doses revealed obvious aggravation of AOH effect with irradiation. By the 20th session of irradiation overall free amino acid content increased to 30 mg% (19.5 mg% after 10 sessions).

In the 3d group of subjects (3 biodoses UVR combined with 2-h AOH), there were the same changes in total free amino acid content of plasma after the 10th irradiation, as compared to baseline values and parameters for the 1st group. Amino acid pool declined to 19.7 mg% (baseline period 25.1 mg%). This was attributable to reliable decline of levels of leucine, methionine, phenylalanine, cystine, aspartic acid, glutamic acid, glycine, alanine and arginine with concurrent reliable rise in threonine.

After 20 sessions of irradiation, the 3d group of subjects presented a noticeable increase in plasma amino acid pool--to 31.2 mg% (background 25.1 mg%, 1st group 20.4 mg%). This was due to reliable increase in plasma isoleucine, leucine, tyrosine, aspartic acid, lysine and arginine, with reliable decline of threonine, cystine and glycine (see Table). On the 13th day of the recovery period after 20 UVR there was insignificant equalization of amino acid balance, and the amino acid pool constituted 28.5% [probably typo for mg%].

Comparative analysis of parameters for subjects in the 2d and 3d groups revealed that, regardless of radiation dosage, there were analogous changes in amino acid spectrum of blood plasma. Thus, after 10 UVR subjects in the 2d and 3d groups presented insignificant decline of the amino acid pool in blood, which is inherent in stress situations [2]. Conversely, irradiation (20 sessions) of the same groups shifted amino acid balance in the direction of accumulation of

free amino acids in blood, which is typical of long-term hypokinesia [1, 3]. It should be noted that, in spite of the brief hypokinesia, in this test (2-h AOH only during UVR) we obtained after the 20th irradiation session marked changes in amino acid spectrum of blood indicative of attenuation of anabolic processes and prevalence of catabolic ones.

Thus, short-term AOH (-12°) and 10 sessions of UVR combined with AOH act as a stress stimulus leading to reduction of blood plasma amino acid pool. The change in amino acid balance does not depend on UVR dosage: identical results were obtained after both 10 and 20 sessions of UVR. Twenty sessions of UVR combined with 2-h AOH (-12°) elicited an increase in free amino acid pool of blood, due to attenuation of anabolic processes and prevalence of catabolic ones. The recovery period was not long enough for amino acid balance to return to normal.

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UDC: 629.78:612.647

GENERAL DESCRIPTION OF EXPERIMENT DEALING WITH RAT ONTOGENESIS ABOARD COSMOS-1514 BIOSATELLITE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 27 Mar 84) pp 49-53

[Article by L. V. Serova, L. A. Denisova, Z. I. Apanasenko, L. A. Bryantseva and N. A. Chel'naya]

[English abstract from source] Ten female Wistar rats were exposed to zero-g during 5 days, i.e. from gestation day 13 to day 18. After recovery the flight animals showed a significant delay in weight gain, thymus involution, decreased liver weight, hemoglobin concentration. Nevertheless, their reproductive function did not differ from that of the controls: the rate of pre-implantation and total fetal mortality as well as the number of live fetuses were very similar in the experimental and control animals. The flight group showed a slight decline of fetal weight and water content. The size of the litters produced by the flight and control rats was identical but the mortality rate of those former during the first 7 days after birth was significantly higher.

This experiment has demonstrated that the mammalian fetus exposed to zero-g during the last term of pregnancy, i.e., at the stage of active organogenesis, can grow and develop in the normal way. A large body of biological material has been obtained for biochemical and histological examinations that will help evaluate the condition of dams, fetuses and newborns.

[Text] The purpose of the embryological experiment with mammals, which was performed for the first time aboard Cosmos-1514 biosatellite, was to assess the effect of weightlessness on prenatal development in the last third of the gestation period, the period of active organogenesis. There is no information on this score in the literature. Embryological experiments with insects, fish and amphibians conducted in weightlessness and its simulation on a clinostat [1, 2, 8, 11, 13] could hardly be used even for an approximate prediction of development under such conditions of mammals, due to their greater sensitivity to environmental factors [10] and complexity of reciprocal influences in the mother-fetus system.

Previously, in a study of adult animals flown aborad biosatellites of the Cosmos series, changes were found that, having appeared in the mother, could have an adverse effect on fetal development. They include, in particular, osteoporosis, involution of lymphoid organs, depression of erythroid hemopoiesis and many others [3-5, 12].

Development of a fetus is related to significant activation of anabolic processes. Questions of the extent to which this is possible in weightlessness, when there is general intensification of catabolism in an adult animal and how organogenesis (in particular, development of bone) will proceed when there is a calcium deficiency in the mother remain open. They were used as the basis of our program for an embryological experiment with mammals aboard Cosmos-1514.

Methods

We used female Wistar rats about 4 months of age, weighing 280-310 g, in the experiment. The animals were prepared for the flight following a special system, which included a clinical and physiological examination (determination of general condition, dynamics of body weight, hematological and microbiological tests), evaluation of estral cycles, conditioning for life in regular upkeep systems and formation of groups (evaluation of compatibility) 10-12 days before the flight.

The female rats of the flight group were fertilized on the ground before the experiment. For this, females with a distinctly established estral cycle were placed with males, the fertility of which had been evaluated in advance, in a ratio of 1♂:3♀. The day of demonstration of spermatozoa in a vaginal smear was considered the first day of the gestation period. On the day of the launch, gestation constituted 12 complete days and was in the start of the 13th, and on landing day it constituted 17 full days, start of the 18th.

During the flight, which lasted 5 days, 10 of the pregnant rats were kept as a group in a cage of the BIOS-vivarium unit 160×220×660 mm in size. The animals were given special paste-like feed [7] at the rate of 55 g (94.5 kcalories) per rat per day, and water. Daylight lasted 16 h during the flight. Ambient temperature was in the range of 20-24°C, pO_2 150-210 mm Hg and pCO_2 to 1.5 mm Hg.

We used 3 groups of control animals: vivarium control--25 rats; baseline control dissected on the day of the launch to evaluate initial fertility and general condition of the animals--30 rats; synchronous control in a mock-up of the biosatellite (10 rats), where we simulated the onboard upkeep conditions, as well as the effect of some physiologically significant factors related to the launch (vibration, linear accelerations) and landing (brief impact accelerations when "jettisoning" the hatch of the parachute container).

On the last day of the flight (18th day of gestation) we decapitated 5 females and counted their corporal lutea, determined sites of implantation, resorption, live, dead and abnormal fetuses, weight and hydration of fetuses and placenta. Material was taken for subsequent examination of viscera of females and fetuses by embryophysiological, morphological and biochemical methods.

We left five rats of the flight group until the time of natural parturition. On the day of birth, the litters were equalized to 8 offspring in each. We monitored their growth and development, blood findings, behavior and work capacity. In this time, the animals were given water and special feed ad lib; after the baby rats reached the age of 10 days we supplemented the special feed given to the mothers with mixed feed--grain, cottage cheese, green and other vegetables.

Results and Discussion

Before the flight, the animlas' condition was quite satisfactory. They grew well and their blood findings were within the normal range. Dissection of rats in the baseline control group on launch day failed to reveal changes in internal organs. Progress of pregnancy was normal.

When the animals were removed from the BIOS-vivarium unit on landing day, we found that their fur and tails were soiled with feed. Nevertheless, their general condition was satisfactory: they were active and mobile. Dissection failed to demonstrate pathological changes in organs of the chest and abdomen.

During the experiment (from 13th to 18th day of gestation) the flight group of rats gained only 5 g and those in the synchronous control, 65 g, which corresponds to normal weight gain at this stage of pregnancy. Feed intake was virtually the same in the flight and synchronous groups: average of 54 and 57 g per day, per rat, respectively.

The flight group of animals presented a drop in weight of the thymus to 238 mg, versus 338 mg in the vivarium control and 273 in animals of the synchronous control ($P<0.05$). Analogous findings were made when we counted lymphocytes in the thymus (thymocytes); the total was 733 million in the experiment, versus 1149 million in the vivarium control and 1044 million in the synchronous control.

The flight group showed a tendency toward increase in adrenal weight to 92.8 mg, versus 82.3 mg in the vivarium control and 79.8 mg in the synchronous control ($P>0.05$).

We were impressed by the very large spleen in the rat population used in this experiment. The spleen weighed 2.68 g in animals of the vivarium control, 1.06 in flight animals and 1.57 g in the synchronous control.

Absolute weight of the liver was reliably lower in rats of the flight group than in those of the synchronous and vivarium controls, and it constituted 10.3 g. An analogous pattern was observed when we measured the relative mass of the liver, although here the differences between groups were less marked: weight of the liver constituted 3.52% of body weight in the flight group, 4.11% in the synchronous control and 3.83% in the vivarium control. The difference between experimental and synchronous control animals was reliable.

Absolute weight of the kidneys was the same in all groups of females, but since the experimental group gained virtually no weight during the flight

the relative weight of their kidneys at the end of the experiment was greater than in control animals.

Blood hemoglobin concentration was 9.8% in the flight group of females was reliably lower than in the vivarium and synchronous controls (12.9 and 13.4 g%, respectively).

In spite of the fact that the flight group of females presented significant weight retardation from control animals and presented a number of other adverse changes, as compared to the control (such as, for example, involution of the thymus and anemia), the basic parameters of reproductive function were not altered. We failed to demonstrate reliable differences between rats submitted to weightlessness and those in vivarium and synchronous control groups with respect to number of corpora lutea, sites of implantation and resorptions. Preimplantation and general embryonic mortality was virtually the same in all groups (Table 1). Live births averaged 13 per female in the experimental group, with 13 in the synchronous and 12 in the vivarium control. Necropsy on the 18th day of the gestation period failed to reveal dead fetuses in any of the groups; however, in both the experimental and synchronous control groups there was an increase in number of fetuses and placentas with abnormalities (Table 2), consisting mainly of hemorrhages apparently related to the brief exposure to impact accelerations when "jettisoning" the hatch of the satellite's parachute container.

Table 1. Parameters of reproduction function of female rats (M±m)

ANIMAL GROUP	NUMBER OF FEMALES	CORPORA LUTEA	IMPLANTATION SITES	RESORPTION	LIVE FETUSES	DEAD FETUSES	PREIMPLANTATION MORTALITY %	OVERALL EMBRYO MORTALITY %	AMNIOTIC FLUID, G
FLIGHT	5	15.8±1.0	14.8±0.7	1.2±0.4	13.6±0.8	0	5.8±2.6	13.4±4.1	0.89±0.02*
SYNCHRONOUS CONTROL	5	16.0±0.8	14.4±0.7	1.0±0.4	13.4±1.0	0	9.9±2.8	16.4±4.4	1.05±0.03
VIVARIUM CONTROL	7	14.9±0.4	13.0±0.8	0.57±0.29	12.4±0.9	0	12.3±4.7	16.4±4.8	1.04±0.03

* $P_{V,S} < 0.01$.

Table 2. Some characteristics of fetuses and placentas on 18th day of gestation period

ANIMAL GROUP	NUMBER OF FEMALES	NUMB. OF FETUSES	WEIGHT OF FETUS G	TOTAL FETAL WEIGHT G	WEIGHT OF PLACENTA G	FLUID CONTENT KG/KG DRY WEIGHT		HEMORRHAGES %	
						FETUS	PLACENTA	FETUS	PLACENTA
FLIGHT	5	68	0.84±0.03*	11.4±0.22	0.31±0.02*	9.55±0.16	5.97±0.19	38.8**	11**
SYNCHRONOUS CONTROL	5	67	0.94±0.02	12.49±0.99	0.37±0.01	9.03±0.12	5.96±0.15	25.4**	7.6**
VIVARIUM CONTROL	7	87	0.92±0.03	11.47±0.90	0.38±0.025	9.04±0.03	5.94±0.11	1	0

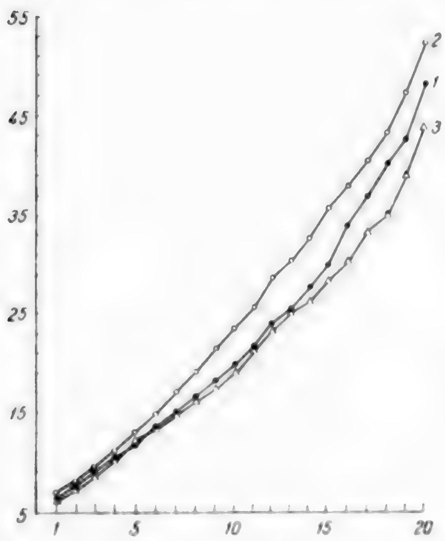
* $P_S < 0.05$.
** $P_V < 0.001$.

Average fetus weight was 0.84 g in the experiment, which was lower than in the synchronous and vivarium controls (see Table 2); fluid content in fetal tissues was reliably higher in flight group animals than in the controls. Mean weight of the placenta was 0.31 g in the experimental group, which was lower than in the synchronous and vivarium controls; placental hydration was the same in all groups (see Table 2). There was reliably less amniotic fluid in flight group animals than in controls (see Table 1).

Live offspring was obtained from 4 out of the 5 animals in the flight group that were kept unitl natural birthing. The quantity averaged 12 per female, with 12 per female in the synchronous control and 10 in the vivarium control. Gestation period was longer in animals of the experimental group than in controls; labor was much more difficult in flight group rats; apparently this was related to the decline of systemic resistance of animals exposed to weightlessness, as well as changes in their muscles.

One of the flight group rats gave birth to dead offspring, which could be attributed to difficult delivery and presence of one very large fetus; the other fetuses apparently perished due to asphyxia as a result of the long interval between separation of placenta and exit from the uterus. All of the fetuses of this female were carried to term, without visible abnormalities, with the exception of the largest one, which had a large fresh hematoma on the head that apparently appeared at birth.

Five other rats had one dead offspring each--2 females from the flight group, 2 from the vivarium control and 1 from the synchronous control.



Dynamics of changes in offspring weight in the postnatal period
X-axis, day of life; y-axis, body weight (g)
1) experiment
2,3) vivarium and synchronous controls, respectively

Average neonate weight was 5.9 g in the experiment, 5.6 g in the synchronous control and 6.4 g in the vivarium control. There was a reliable decrease in absolute weight of the liver in experimental group neonates, as compared to the control; fluid content in liver tissue was the same in all cases. Blood hemoglobin concentration was 10.6 g% in neonates, and it was reliably lower than in the vivarium and synchronous controls (11.4 and 11.7 g%, respectively).

We kept 8 baby rats from each female in the flight, vivarium and synchronous groups for physiological studies in the postnatal period. However, their mortality rate in the 1st week of life was considerably higher in the experimental group than the controls; it constituted 19%, versus 0% in the vivarium group and 2.5% in the synchronous group. In the first 20 days of the postnatal period, baby rat weight continued to be lower in the experimental group than

in the vivarium control, but was higher than in the synchronous control (see Figure). No appreciable or stable differences in water and feed intake were demonstrable between the groups.

In spite of some retardation in development of flight group offspring, as compared to the vivarium control, their development did not lag behind the control with regard to some parameters and sometimes was ahead. For example, there was virtually the same time of development of fur in experimental and vivarium control animals, while those in the experimental group opened their eyes even earlier, on the 13th-15th day of postnatal life, versus 14th-16th day in the control. On the 14th day, the eyes were open in 65% of the experimental rats and only 35% of the controls.

Our findings demonstrate for the first time the possibility of development of a mammalian fetus in weightlessness in the last third of the gestation period, at the stage of active organogenesis.

In spite of the high fertility of flight group animals, the difference between them and the control is evident even now, at the very first stage of analysis of the results. The impression is gained that this difference was smallest at the stage of examination of fetuses, increasing at the time of birth and even more in the postnatal period. We were impressed primarily by the high early postnatal mortality in the flight group.

Since vital organs of flight group offspring developed in weightlessness, one could expect that the differences between them and the control would progress as the organs develop and carry an increasing work load. The large volume of physiological, biochemical and morphological studies scheduled for different stages of postnatal development of rats up to puberty should help answer these questions.

It should be noted that the protocol of the embryological experiment was prepared with consideration of critical (most sensitive to damage) periods of development [6, 9]. In the first experiment, the purpose of which was to determine whether a mammalian fetus could develop during a spaceflight, we deliberately selected the most resistant period of development for exposure to weightlessness. In the future, it would be desirable to assess the effect of weightlessness on earlier stages of prenatal development, and we can expect greater changes in the mother-fetus system than in this experiment.

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UDC: 629.78:612.766.2-08

MORPHOLOGICAL STUDY OF ANTIORTHOSTATIC HYPOKINESIA IN MONKEYS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 18 Oct 83) pp 53-60

[Article by A. S. Kaplanskiy, Ye. A. Savina, P. B. Kazakova, I. P. Khoroshilova-Maslova, G. M. Kharin, V. I. Yakovleva, G. I. Plakhuta-Plakutina, G. N. Durnova, Ye. I. Il'ina-Kakuyeva, Ye. I. Alekseyev, A. S. Pankova, V. N. Shvets and T. Ye. Burkovskaya]

[English abstract from source] Morphological examinations of rhesus monkeys (Macaca mulatta) exposed to head-down tilt for 7 and 19 days are summarized. The major changes detected in various systems, organs and tissues are described. The changes are thought to be of different origin and caused by blood redistribution, hypokinesia per se and concomitant stress. It is emphasized that head-down tilt is one of the most adequate methods for simulating effects of zero-g in monkeys.

[Text] There are a number of limitations when conducting clinicophysiological, biochemical and morphological studies aboard a spacecraft, so that it becomes necessary to simulate flight conditions on the ground, particularly weightlessness. One of the best models of weightlessness is antiorthostatic hypokinesia (AOH), with which it is possible to reproduce the redistribution of blood in the body inherent in weightlessness and shortage of dynamic and static loads on the skeletomuscular system [3, 4, 11]. As for morphological changes that occur with AOH, we know virtually nothing on this score since the nature of clinical symptoms with AOH is not clear: Is it purely functional, or is it based on certain structural changes? For this reason, it is of great theoretical and clinical interest to conduct a comprehensive morphological study of monkeys submitted to AOH.

Methods

We are summarizing here the results of morphological studies of Macaca mulatta monkeys submitted to AOH for 7 and 19 days with the head-down tilt of -6° using a method developed at the Institute of Experimental Pathology and Therapy, USSR Academy of Medical Sciences [15]. We used 12 monkeys in the experiment, 6 of which spent 19 days and 2 spent 7 days under AOH conditions, and 4 animals served as a control. The animals were sacrificed under anesthesia by intravenous injection of 3-4 mℓ 10% hexenal solution.

Results and Discussion

Necropsy revealed dilatation and plethora of vessels of the dura and pia, brain and spinal cord, deep and superficial veins of the neck and shoulder girdle, marked plethora of the thyroid, lungs, myocardium, liver and kidneys in all monkeys of experimental groups. Plethora was apparently the chief cause of increase in weight of organs (see Table). At the same time, muscles of the skeleton and particularly the lower extremities appeared anemic at autopsy, and their mass was diminished; there was substantial variation of weight loss in muscles differing in functions (see Table). Body weight loss was observed only in monkeys submitted to 19-day AOH. Disappearance of fat from the reservoirs (subcutaneous fatty tissue, greater omentum) was noted in all experimental animals. AOH also elicited virtually complete aplasia of the thymus and considerable increase in weight of inguinal lymph nodes.

Changes in weight of viscera and muscles of monkeys submitted to AOH

Organs	Control, g	7-day AOH		19-day AOH	
		g	difference from control, %	g	difference from control, %
Heart	12,10	14,54	+20	13,93	+12
left ventricle	4,74	5,71	+20	5,71	+20
left ventricle and septum	7,79	10,14	+30	9,64	+24
right ventricle	2,42	2,70	+11	2,57	+6
Fulton's index	3,22	3,76	+17	3,73	+16
Lungs	24,80	29,50	+12	32,07	+30
Liver	85,00	97,00	+14	111,50	+20
Kidneys	13,60	17,90	+32	17,40	+28
Spleen	3,29	2,56	—12	3,45	+5
Thymus	2,60	Aplasia		Aplasia	
Inguinal lymph nodes	0,27	0,42	+54	0,47	+71
Adrenals	0,75	0,73	—2	0,76	+2
Brain	92,90	90,60	—2	105,00	+13
Muscles					
gastrocnemius	19,20	20,40	+6	18,21	—5
soleus	5,90	5,73	—3	4,60	—22
femoral quadriceps	56,30	47,70	—15	40,70	—28
brachial biceps	13,30	11,97	—10	12,50	—6

On the whole, the changes demonstrated upon necropsy of monkeys submitted to 7- and 19-day AOH were in the same direction and progressed with increase in duration of AOH. This indicates that, under AOH conditions, in addition to changes due to hypokinesia proper and concomitant stressor reaction, there are distinct signs of redistribution of blood with shifting of a considerable part of the blood into the upper half of the trunk and head.

As shown by the results of microscopic examination, redistribution of blood during AOH is associated with development of static plethora in several organs, primarily the brain and eyes. Thus, under AOH conditions, the monkeys presented not only plethora of medium-sized and small arteries, veins and capillaries of the brain and meninges, but impaired permeability of blood vessels, which led to perivascular edema (Figure 1) and fine diapedetic hemorrhages.

Figure 1.
Perivascular edema in brain of monkey submitted to 19-day AOH. Picrofuchsin stain, magnification 160×

The latter were encountered the most often in the pia mater, hippocampus, cerebellum and subependymal region. Cerebral hypoxia, which accompanied the microcirculatory disturbances, was most probably the chief etiological factor in the dystrophic changes encountered in some neurons (Figure 2) and neuroglial cells of monkeys submitted to AOH. The severity of dystrophic changes in neurons varied from case to case, but in the majority they were reversible as, incidentally, were the microcirculatory disorders. Increased delivery of blood to the brain was apparently associated with elevation of intracranial pressure, since x-ray analysis of bones of the cranial fornix revealed accentuation of the pattern of digitate impressions.

Hemodynamic disorders similar to those found in the brain were also found upon examination of the eyes, which presented static plethora of all calibers of retinal vessels, some diapedetic hemorrhages in the vitreous body and retina, edema and accumulation of micropinocytotic blebs in the capillary endothelium (Figure 3). In addition, we often encountered capillaries of the "closed" type, the acellular wall component of which was friable and thickened, while the endothelial cells protruded into the lumen of the capillary, closing it almost entirely. The dystrophic changes concomitant with static plethora were noted in the endothelium and myocytes of vessels (Figure 4) but not in the retinal parenchyma.

Although the vessels of the thyroid, lungs, heart and liver were plethoric, there were no signs of impaired permeability of vascular walls. Perivascular edema and diapedesis were also absent from the above-mentioned organs. In the thyroid, dilated and plethoric capillaries were demonstrable primarily in the perifollicular region. In the lungs, deposition of blood was observed mainly in capillaries and veins; the convoluted and dilated capillaries formed lacuna-like dilatations in some areas, protruding into the alveolar lumen; the fine arteries of the lungs were plethoric. Morphometry of fine pulmonary arteries revealed that the cross section of their muscular tunic did not change under AOH conditions, whereas the Karnogen index decreases, which is indicative of change in tonus of arteries of the muscular type. Some thickening and coarsening of elastic fibers in the wall of small arteries and veins of the lungs were indicative of appearance of early signs of a compensatory and adaptive reaction of vascular walls to hypervolemia in the pulmonary circulatory system.

Deposition of blood in the myocardium of monkeys submitted to AOH occurred primarily in thebesian vessels, and maximum plethora was demonstrated in thebesian vessels of the left heart. The predominant plethora of thebesian

vessels of the left heart is apparently attributable to the fact that, with hypervolemia in the pulmonary circulatory system, most of the myocardial venous blood is ejected over the system of thebesian vessels into the left chambers. Under normal conditions, most of the myocardial venous blood passes through the coronary sinus into the right atrial chamber. In addition, the possibility cannot be ruled out that, with plethora of the pulmonary circulatory system, some of the blood from the right heart chambers is transferred via thebesian vessels into the left chambers, bypassing the lungs. This reduces the load on the right heart and helps equalize pressure in chambers of the right and left heart [12]. It should also be noted that we did not observe any appreciable changes in the myocardial capillary network when monkeys were submitted to AOH and that no hypertrophy of the right heart was demonstrable, in spite of hypervolemia in the pulmonary circulation.

Figure 2. Dystrophic changes in neurons of the monkey brain with 19-day AOH

a) cytoplasmic swelling and tigrolysis in Betz cells of the cortex; Nissl's thionin stain; magnification 160×
b) shadow cells (shown by arrows) in cerebellar dentate nucleus; Nissl's thionin stain; magnification 100×

Deposition of blood in the monkey's liver under AOH conditions led to drastic dilatation and plethora of vessels in the system of the portal vein and septal veins.

AOH elicited redistribution not only of blood in the body, but lymph, as indicated by the increase in weight of inguinal lymph nodes, dilatation and

filling with lymph of their sinuses and efferent lymphatic vessels. Accumulation of lymph in inguinal lymph nodes could have been due to more intensive influx from the lower extremities because of antiorthostatic position.

Figure 3.
Intracellular edema and accumulation of micropinocytotic vesicles in endothelial cell of retinal capillary in monkey submitted to 19-day AOH

Figure 4.
Dystrophic mitochondrial changes (formation of myelin corpuscles) in muscle cells of choroideal arterioles in monkey submitted to 19-day AOH

Electron micrographs, magnification 32,000×

Thus, the submitted data indicate that under AOH conditions monkeys present redistribution of blood associated with impairment of blood circulation and development of static plethora in several organs. The hypoxic syndrome, which is an inevitable finding with static plethora, leads to development of dystrophic changes which are mostly reversible. The question of what would happen with longer AOH--aggravation of hemodynamic disorders and dystrophic changes or gradual normalization as a result of development of adaptive and compensatory reactions--remains open and requires experimental verification.

The most significant changes caused by hypokinesia proper were observed in the skeletomuscular system. As shown by comprehensive histological and morphometric studies, exposure of monkeys to AOH for 19 days led to development of changes in long bones (tibia) that could be generally qualified as early osteoporosis. The following facts attest to this: increased vascularization of compact bone, enlargement of osteons and haversian canals, increase in number of zones of sinus-like bone resorption, reduction in relative area of compact bone and,

to a lesser extent, of spongy bone, destruction of osteons and widening of bone marrow canals. Development of osteoporosis was the result of more intensive resorption of bone tissue, although inhibition of osteogenesis had also apparently occurred, since the relative area of the metaphyseal growth plate had diminished in experimental animals. Similar bone changes had also been found by other authors [19] in monkeys submitted to 14-day hypokinesia.

Appreciable changes were also observed in skeletal muscles. Reduction of their weight (gastrocnemius, soleus, brachial biceps) with concurrent decrease in diameter of muscle fibers (particularly red ones) was indicative of development of an atrophic process in muscles under the influence of hypokinesia. The decrease in number of functional capillaries in muscles was apparently related to the smaller physical load on muscles, and it was observed only in muscles of the lower extremities, whereas in the brachial biceps there was no change in number of functional capillaries.

Inhibition of erythroid hemopoiesis in bone marrow of monkeys submitted to AOH should also be interpreted as a manifestation of the hypokinetic syndrome; it had been repeatedly observed in man and animals under both hypokinetic and spaceflight conditions [2, 8, 9, 11, 13, 16] and is apparently related to insufficient muscular activity.

Restriction of the monkeys' movements and redistribution of fluids during AOH could not help but affect functions of the neuroendocrine system responsible for hormonal regulation of metabolism and maintaining homeostasis. A study of the hypothalamo-hypophyseal neurosecretory system (HHNS) involved in regulating hemodynamics and fluid-electrolyte metabolism revealed that, on the 7th day of AOH, in the main elements of the HHNS there was deposition of neurosecretions against the background of spasm of blood vessels. Accumulation of neurosecretions in neurons, axons and nerve endings is apparently related to impaired release of ADH-vasopressin into blood and is caused by elevation of transmural pressure in the region of volumobaroreceptors (left atrium--pulmonary artery) [1, 23] and intensification of flow of impulses having an inhibitory effect on the HHNS as a whole and on the level of ADH-vasopressin secretion in particular [20]. As AOH exposure time increased, there was decline in neurosecretion content of HHNS structures and, at the same time, we observed activation of neurosecretion synthesis, as indicated by enlargement of neurons and their nuclei.

Thus, with increase in duration of AOH the initial phase of deposition of neurosecretions is followed by a phase of activation of ADH-vasopressin release, which is instrumental in establishing a new level of fluid metabolism and stabilization of hemodynamics under AOH conditions.

Aside from the above-mentioned changes due to disturbances referable to hemodynamics and fluid metabolism, the hypophysis of monkeys submitted to AOH presented changes in the somatotroph system, i.e., cells that produce growth hormone. At the early stages of AOH we observed more intensive degranulation of somatotrophs and decreased oxyphilia of their cytoplasm, whereas on the 19th day of the experiment we demonstrated greater oxyphilia of somatotroph cytoplasm and increase in their size (we did not observe enlargement of somatotroph nuclei). It should be borne in mind that there is a correlation between

oxyphilia of somatotrophs and levels of growth hormone in them [21, 22]; one should consider that phasic changes are observed in the hypophysis of monkeys submitted to AOH in growth hormone levels and that, on the 7th day of AOH, there is increased secretion whereas on the 19th day there is inhibition of secretion of growth hormone. These data are consistent, to some extent, with the results of assaying growth hormone in blood of people who spent 49-56 days under hypokinetic conditions, in whom blood growth hormone concentration decreased at the start of the experiment, increased drastically on the 14th-20th day and then persistently decreased to the end of the experiment [17, 24]. The causes and physiological purpose of inhibition of growth hormone secretion during hypokinesia are unclear, although we cannot rule out the possibility that hypokinetic stress with its inherent intensified steroid production elicits depression of somatotroph function. In any case, impaired function of somatotrophs under hypokinetic conditions is very consistent with the numerous findings indicative of the fact that there is inhibition of animal growth during long-term hypokinesia [10, 13].

Substantial changes were also demonstrated in endocrine glands involved in controlling calcium metabolism under the effect of AOH. Thus, at the early stage of AOH, the monkey's thyroid presented distinct signs of increased functional activity of C cells, which produce calcitonin, as manifested by enlargement of C cells and their nuclei, accumulation of specific secretory granules in cell cytoplasm, hyperplasia of Golgi's complex, structures of the endoplasmic reticulum and mitochondria. At the end of the experiment, among C cells there was prevalence of degranulated forms, which was indicative of intensified hormone secretion. On the 7th and particularly 19th day of the experiment, the parathyroid glands that produce parathyroid hormone presented signs of increased functional activity, as indicated by enlargement of nuclei and nucleoli of parathyrocytes, as well as capillary plethora in the gland. The data concerning activation of parathyroid function in monkeys submitted to AOH confirm the findings of other authors, who demonstrated that there is considerable increase in blood parathyroid hormone concentration in hypokinetic monkeys and man submitted to AOH [7, 17]. The increase in activity of monkeys' C cells and parathyrocytes during AOH is an indirect indication of changes in calcium metabolism, and it has a direct bearing on developing osteoporosis.

AOH, as any other form of experimental hypokinesia, elicited in monkeys the development of an acute stressor reaction with its typical changes in the adrenals and lymphoid organs. The adrenals of experimental animals presented hypertrophy of the fascicular zone of the cortex, enlargement of nuclei in cells of the fascicular zone, decrease in triglyceride and cholesterol levels, increased activity of 3β-ol-steroid dehydrogenase in fascicular zone cells, i.e., we observed signs indicative of increased production and secretion of corticosteroids. The changes in the adrenal cortex were not limited to the fascicular zone, and extended to the glomerular zone as well, in the cells of which signs of increased functional activity (hypertrophy of cells and their nuclei, accumulation of lipids in cytoplasm) were noted on the 19th day of AOH. Since it is known that glomerular cells produce aldosterone, it can be assumed that increase in their functional activity was related to intensification of production of this mineralocorticoid, which is involved in regulation of fluid-electrolyte metabolism and intensified production of which had been observed during AOH and clinostatic hypokinesia in people [5, 6].

The stressor effect of AOH was less marked in the monkeys' adrenal medulla than in the cortex, and it was manifested by some stimulation of catecholamine synthesis on the 7th day of AOH. This was indicated by the enlargement of chromaffine cell nuclei and increase in number of cells producing norepinephrine on the 19th day of AOH. The changes demonstrated in the adrenals of monkeys submitted to AOH are an expression of adaptive reactions, some of which are a reflection of stress, while others develop in response to hemodynamic changes and fluid-electrolyte metabolic disorders. In lymphoid organs, accidental involution of the thymus and hypoplasia of lymphatic tissue of the spleen were indicative of a stressor reaction to AOH.

The increase in functional activity of systems responsible for development of the general adaptation syndrome apparently persisted throughout the experiment, since the size of cell nuclei in the fascicular zone of the adrenal cortex of experimental animals remained enlarged on the 19th day of AOH, and there was no normalization of cholesterol content, or of lipids in the adrenal fascicular zone. The increased activity of the adrenal cortex caused faster development of the body's response to a repeated stressor. This was manifested by neutrophil infiltration of splenic red pulp and neutrophilia of peripheral blood (signs of acute stress) in experimental monkeys. Control animals submitted to the same stressogenic factors showed no neutrophil reaction in blood and spleen.

In addition to the changes elicited by stress, we demonstrated marked plasma cell hyperplasia in the spleen and lymph nodes of monkeys submitted to AOH; this is a morphological expression of an immune process indicative of active synthesis of antibodies. Since the animals examined were essentially healthy, plasmatization in their lymphoid organs can be interpreted as a manifestation of an autoimmune reaction arising due to sensitization of the body by products of tissue breakdown. Appearance of antibodies against murine tissue antigens in the blood of hypokinetic rats is indicative of the validity of the latter assumption [14].

To sum up all of the foregoing, it can be stated that a set of changes is observed in parenchymatous organs, the skeletomuscular system and neuroendocrine regulatory system of monkeys submitted to AOH, which are the result of redistribution of blood in the body, hypokinesia proper and stress that arises due to immobilization of the animals combined with antiorthostatic position of the body. On the whole, one should consider that AOH of monkeys is one of the best experimental models of weightlessness.

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UDC: 629.78: [612.129:577.175

RAT PLASMA HORMONE LEVELS FOLLOWING FLIGHT ABOARD COSMOS-1129 BIOSATELLITE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 19 Jul 83) pp 60-64

[Article by R. A. Tigranyan, N. F. Kalita, L. Macho and R. Kvetnansky (USSR and CSSR)]

[English abstract from source] The concentration of ACTH, insulin, glucagon, glucose, epinephrine, norepinephrine, thyrotrophic hormone, thyroxine, and triiodothyronine was measured in plasma of the rats flown for 18.5 days on Cosmos-1129. As a result of the flight, the concentration of insulin, thyrotrophic hormone, and triiodothyronine increased and that of thyroxine decreased. It is suggested that the above changes have been induced by an acute stress associated with biosatellite reentry and touchdown.

[Text] Experiments conducted aboard biosatellites of the Cosmos series revealed several signs of activation of the rat's endocrine system, which occurred under the effect of the set of spaceflight factors and rapid return to earth's gravity [2, 7, 8]. These changes in hormonal status of rats were associated with some changes in concentrations of several hormones in blood. Thus, the results of assays of concentration of corticosterone (B) in rat plasma after completion of experiments aboard Cosmos-605, Cosmos-690 and Cosmos-782 showed that the first postflight hours are associated with elevation of B level, after which plasma B level drops and 24 h after the spaceflight it was already considerably lower than the control level [3, 9, 14]. At the same time, the spaceflight aboard Cosmos-782 did not elicit noticeable changes in concentrations of a number of hormones (ACTH, prolactin, thyrotropic, follicle-stimulating, luteinizing and melanocyte-stimulating hormones) in blood plasma [15]. The spaceflight aboard Cosmos-936 was associated with increase in concentration of B, insuline and decrease in thyrotropic hormone (TTH) content in plasma of rats submitted to weightlessness, as well as elevation of thyroxine (T_4) level in plasma of rats submitted to artificial gravity in flight; concentrations of ACTH, testosterone and triiodothyronine (T_3) in plasma did not undergo appreciable change [10-12]. At the same time, the flight aboard Cosmos-936 biosatellite elicited a significant elevation of epinephrine (E) and norepinephrine (NE) levels in rat plasma both in weightlessness and with use of artificial gravity [6].

Our objective here was to examine the levels of several hormones in blood plasma of rats after flight aboard Cosmos-1129 with consideration of rate of repair of previously demonstrated changes with shortening of the recovery period, as well as the effect of repeated stress in the recovery period on response of the parameters of the rat's hormonal status that we examined.

Methods

The studies were conducted on male Wistar-SPF (Bratislava, CSSR) rats flown for 18.5 days in space aboard Cosmos-1129 biosatellite. The animals were submitted to euthanasia 6-8 h after landing and on the 6th day after the flight; some of the animals examined on the 6th postflight day were submitted to immobilization stress 5 times (150 min daily); rats in the control and synchronous groups were also submitted to repeated immobilization stress. We assayed plasma concentrations of ACTH, insulin, TTH, T_4, T_3 and glucagon by the method of radioimmune analysis, glucose content by an enzymatic method [17] and levels of E and NE by a radioenzymatic method [6]. Statistical reliability was calculated using Student's *t*-test.

Results and Discussion

Animals examined immediately after landing showed no difference in blood ACTH level, as compared to rats in the vivarium control and synchronous experiment (see Table). Analogous findings were made in the experiments aboard Cosmos-782 [15] and Cosmos-936 [10-12]. On L+6, blood ACTH content in flight rats did not differ from the level of this hormone in animals of the vivarium control. The rats used in the synchronous experiment showed drastic increase in ACTH concentration, as compared to both the vivarium control and flight experiment (see Table), which was apparently related to manipulations prior to decapitation of the animals. The absence of noticeable postflight changes in ACTH level could have been due to the inhibitory effect on ACTH secretion of the elevated BC [expansion unknown] level in this period [5] via the feedback system.

Repeated immobilization in the postexperimental period was associated with considerable elevation of blood ACTH level in all groups of rats, but more so in the vivarium control (see Table), which most probably could be related to change in sensitivity of the hypothalamus-hypophysis system to the additional stressor in flight animals and rats used in the synchronous experiment.

Plasma insulin level rose significantly immediately after the experiment only in the flight group of rats, remaining elevated also on the 6th day of the recovery period (see Table). An analogous change in blood insulin content following spaceflights had been demonstrated in the experiment aboard Cosmos-936 [10] and in cosmonauts who had made spaceflights aboard Soyuz series spacecraft [13]. However, the high insulin level in flight animals immediately after landing cannot be related to changes in blood glucose and glucagon content, since the concentrations of the latter in blood was on the level of control values at this time (see Table). Elevation of insulin level could be related to its capacity to activate lipogenetic processes, since flight animals presented a significant increase in blood triglyceride content immediately after the flight [1]. At the same time, on the 6th day after the experiment, when blood glucose was unchanged, in all groups of rats and insulin level was

elevated in flight animals, glucagon content increased noticeably, more so in flight animals (see Table). In all likelihood, expressly this correlation between insulin and glucagon levels was instrumental in the unchanged blood glucose at both tested times in experimental groups of animals.

Blood hormone and glucose content in rats used in experiment aboard Cosmos-1129 (M±m)

Parameter	Animal group	1	2	3
ACTH, pg/mℓ	VC	51.10±11.12	36.80±5.21	311.83±58.33[в]
	F	55.40±8.15	58.20±13.75[б]	361.43±52.93[в]
	SE	52.60±6.18	198.70±26.43[a]	451.40±58.65[в]
Insulin, μUA/mℓ	VC	12.36±1.24	17.70±2.00	20.78±2.85
	F	26.93±3.16[a]	26.18±2.96[a]	23.43±5.12
	SE	20.93±4.11	23.08±3.29	25.93±6.01
Glucagon, pg/mℓ	VC	118.9±5.14	143.8±8.62	188.1±10.37[в]
	F	128.0±8.62	241.7±10.11[a,б]	113.6±11.16[a,б,в]
	SE	120.3±7.16	180.6±9.60[a]	260.4±12.0[a,в]
Glucose, mg%	VC	78.16±3.19	84.42±3.71	117.50±10.29[в]
	F	89.92±14.99	91.30±1.69	120.58±10.15[в]
	SE	82.23±12.73	87.78±2.14	104.99±3.43[в]
TTH, μUA/mℓ	VC	1.25±0.33	1.82±0.40	3.56±0.61[в]
	F	8.21±1.62[a,б]	5.30±1.29[a]	5.20±1.00
	SE	3.15±0.69[a]	5.11±0.96[a]	3.42±0.34
T_4, μg%	VC	5,36±0,16	7.42±0.58	4.16±0.40[в]
	F	3.78±0.22[a,б]	6.44±0.30	8.59±0.46[a,б,в]
	SE	8.59±0.35[a]	6.49±0.39	2.39±0.11[a,в]
T_3, ng%	VC	74.71±6.54	46.83±5.10	16.00±1.00[в]
	F	105.33±8.11[a,б]	122.36±9.21[a,б]	123.25±9.0[a,б]
	SE	259.91±12.46[a]	203.64±10.82[a]	93.55±9.69[a,в]
E, ng/mℓ	VC	19.3±1.6	20.8±3.8	11.9±2.4
	F	24.9±3.7[б]	19.9±1.3	10.4±3.0[в]
	SE	13.9±1.1[a]	15.8±1.4	12.1±3.2
NE, ng/mℓ	VC	8.7±1.3	6.6±1.5	7.6±1.6
	F	9.8±1.9	7.2±0.6	12.1±3.4
	SE	5.6±0.8	5.9±0.6	8.6±2.3

Key: VC) vivarium control
F) flight
SE) synchronous experiment
1) 6-8 h after landing
2) 6th day after landing
3) L+6 + immobilization stress
a) reliability as compared to parameters of VC animals
б) same, as compared to SE rats
в) same, when comparing parameters obtained on L+6 and during test with immobilization stress (columns 2 and 3)

UA) units of activity

The test with immobilization stress demonstrated a noticeable elevation of glucose level in all groups of rats; after this test, glucagon content dropped in the flight group of animals and rose in the vivarium control and synchronous experiment groups; it should be noted that insulin level did not change after

immobilization stress in any of the animal groups (see Table). It can be assumed that weightlessness altered the reaction of α cells of the pancreas to a recurrent stressogenic factor.

Immediately after the flight concentration of E in blood plasma increased in flight animals, as compared to values for rats in the synchronous experiment; NE content immediately after the experiment and NE on the 6th day of the post-experimental period in experimental groups did not differ from the control. After the stress test there was a tendency toward decline of E level in the flight group of animals (see Table).

The decline of E and concurrent rise in activity of tyrosine hydroxylase in the adrenals of flight animals submitted to repeated immobilization stress [4] are indicative of increased activity of the adrenal medulla, which should have led to increase in blood E content; however, blood E level was low in these rats. Most probably, the capacity of the adrenal medulla after 5-fold intensive stress was already so depleted that there was no increase in secretion of E; one could have expected substantially greater secretion of E in this group of animals after the first or second immobilization stress.

Investigation of levels of parameters characterizing functional activity of the hypophysis-thyroid system revealed that, immediately after the experiment, there was increase in blood levels of TTH and T_3 in experimental groups of animals. The rise in level of TTH was more marked in the flight group of animals, while concentration of T_3 underwent greater change in rats used in the synchronous experiment. At the same time, T_4 concentration decreased in flight animals and increased in rats of the synchronous control (see Table). In the experiment aboard Cosmos-936, analogous elevation of TTH level was demonstrated, whereas blood T_4 and T_3 content did not change [10].

The test with repeated stress revealed a different reaction of parameters characterizing activity of the hypophysis-thyroid system. Thus, against the background of elevated T_4 in the flight group of animals, there were no changes in TTH and T_3 content, while rats referable to the synchronous and vivarium controls presented a decline of T_3 and T_4; however, TTH level rose in the vivarium control rats and dropped in the synchronous experiment group (see Table). It can be assumed that weightlessness and restricted mobility elicit change in reaction of the hypophysis-thyroid system to repeated stressogenic factors; at the same time, the reaction of this system differed in flight animals, not only from the vivarium control, but the synchronous control also.

Elevation of T_3 level against the background of high TTH content and low T_4 concentration in blood warrants the assumption that there was some decrease in functional activity of the thyroid immediately after the flight. The findings are consistent with the decrease we demonstrated in T_4 content of the thyroid, as well as elevated levels of blood cholesterol and triglycerides [1] in these rats, since it is known that conditions are produced with decline in thyroid activity for development of hypercholesterolemia and hyperlipidemia [16]. It is also known that when thyroxine-producing capacity of the thyroid is diminished there is decrease in inactivating capacity of hepatic glutathione and insulin transhydrogenases, which leads to an increase in blood insulin concentration [18], as we observed in the flight group of rats.

The results of these studies revealed that there is some change in hormonal status of flight animals, while the test with repeated immobilization stress indicates that the rats were affected by an acute stressor most probably related to landing of the biosatellite.

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UDC: 574.682.083

RESULTS OF MICROBIOLOGICAL STUDIES CONDUCTED DURING OPERATION OF SALYUT-6 ORBITAL STATION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 12 Sep 83) pp 64-66

[Article by S. N. Zaloguyev, A. N. Viktorov, V. M. Shilov, V. P. Gorshkov, K. V. Zarubina, M. M. Shinkareva and T. Yu. Norkina]

[English abstract from source] This paper presents the results of microbiological examinations of the Salyut-6 crewmembers and environment. There were few cases of adverse changes in the automicroflora composition, i.e., propagation of staphylococci of a certain biotype among crewmembers. However, no over manifestations of infectious pathology were seen. This allows the conclusion that personal hygiene measures and general hygiene and antiepidemic measures taken before and during Salyut-6 missions were adequate and efficient.

[Text] At the present time the role of the microbial factor during manned spaceflights is being considered in two main aspects. The first is medical, due to the possibility of infectious diseases among crew members, which develop as an autoinfection or so-called cross-infection; the second is biological-engineering, which is related to the possibility of biodestruction of the nonmetal construction materials due to vital functions of microorganisms.

It was previously shown that a specific cenosis of microorganisms is formed in manned pressurized compartments; these microorganisms vegetate on the mucous membranes and integument of people, and they also contaminate the atmosphere, interior and equipment [1, 2, 4].

The operation of Salyut-6 orbital station (OS) for many years made it possible, for the first time, to conduct a set of studies aimed at examining the dynamics of formation of the microflora of cosmonauts' mucous membranes and integument, and the spacecraft environment during activities of the five main crews who worked for different periods of time and a series of visiting expeditions.

Methods

Preflight and postflight analysis of microflora of the mucosa of the nose, mouth and throat, as well as integument of cosmonauts was made by means of repeated collection of specimens using conventional methods [5].

During the flights, specimens of microflora (from the nose, mouth and throat of cosmonauts), as well as from interior surfaces and atmosphere of the OS were collected using special equipment which preserved the microorganisms for the time required to deliver material to earth.

The specimens were cultured on 5% blood agar, mannitol-salt agar, agar with bromothymol blue (for demonstration of Gram-negative bacteria), Kalina's medium and Sabouraud agar. The microorganisms were identified using Bergey's manual [3]. The isolated Staphylococcus aureus cultures were phagotyped using the international set of diagnostic staphylococcal bacteriophages, and we determined the spectrum of their sensitivity to 19 antibiotics.

Results and Discussion

The Table summarizes the main changes in automicroflora of the mucosa of the upper respiratory tract of the members of the main crews recorded in flight or on the day they landed, as compared to results of preflight examinations, as well as the distinctions in composition of microflora of the environment inherent in each phase of operating the OS. Changes in automicroflora of the upper respiratory tract of the cosmonauts (main crews) in flight consisted primarily of appearance on their mucous membranes of microorganisms that were not among the constant representatives of the biotypes of the nasal cavity and mouth of healthy humans. These microorganisms were referable to conditionally pathogenic species--Staphylococcus aureus, β-hemolytic Streptococcus, Enterobacter--klebsiella sp., Pr. mirabilis capable of causing infectious diseases in humans.

In some cases, the mechanism of development of the observed changes in composition of automicroflora of OS cosmonauts was based on transmission and dissemination among crew members of staphylococci of a specific biotype. Individuals previously free of these microorganisms became temporary carriers of staphylococcus on the mucosa of their upper respiratory tract.

This phenomenon is of major scientific and practical significance to comprehension of the basic ecological and hygienic patterns of formation of human microflora when people are confined to sealed areas, and it raises the need to pursue further investigations to demonstrate the biological distinctions of cultures of microorganisms that determine their capacity for epidemic spread in isolated groups.

On the other hand, the obtained data must be taken into consideration when elaborating practical measures to prevent infectious diseases among cosmonauts who participate in the main missions of orbital complexes.

The microflora of the air environment and interior of Salyut-6 OS was represented mainly by epidermal staphylococci and corynebacteria--commensals of the human upper respiratory tract and integument. In addition, we periodically found pathogenic staphylococci, E. coli, bacteria of the species Proteus mirabilis and spores of mold fungi in the samples.

As can be seen in the table, there was some correlation between species composition of microflora in the environment of the orbital station and distinctions

pertaining to the condition of the automicroflora of the upper respiratory tract of crew working in the station.

Changes in composition of automicroflora in members of main crews and microflora of environment in Salyut-6 orbital station

Crew	Mission days	Changes in composition of cosmonauts' microflora as compared to preflight data	Characteristics of environmental microflora
1st	96	Appearance of E. coli and Proteus mirabil. on mucosa of nose; increased number of cultures of antibiotic-resistant staphylococci	Increased general microbial contamination, appearance of staphylococci and P. mirabilis
2d	140	Transmission of phagotype 3C/55 staph. from commander to flight engineer with temporary colonization of his nose by these microorganisms; postflight appearance of β-hemolytic streptococcus on oral mucosa	Presence of phagotype 3C/55 staphylococci; appearance of mold fungus spores
3d	175	Increase in staph. on nasal mucosa; postflight appearance in mouth of Klebsiella pneumoniae and Enterobacter hafnia	Presence of staphylococci (n/t [expansion unknown])
4th	185	Transmission of phagotype 6/47 staph. from member of 1st visiting crew to commander and flight engineer of 4th main crew with colonization of these microorganisms on nasal mucosa	Presence of staph., E. coli, Enterobacter aerogenes, Acinetobacter and mold fungus spores
5th	75	Postflight appearance on oral mucosa of Klebsiella ozenae and Enterobacter hafnia	Presence of staph., E. coli, yeast-like fungi of following species: Penicillium chrysogenum, Aspergillus tamarii, Mucor basis tanicus, Fusarium heterosporum

Direct medical support of cosmonauts aboard Salyut-6 revealed that the extent of microbial contamination of their habitat depended on the nature of general sanitary-hygienic and special disinfection measures implemented by the crews. We failed to establish a link between duration of work aboard the station and intensity of accumulation of microorganisms in the air environment and on interior surfaces. Nor did we detect a direct correlation between flight and crew's work time in the Salyut-6 orbital complex, on the one hand, and extent of changes in composition of their microflora. In spite of the fact that there were some changes in status of the microbiocenoses in the nose and mouth, the cosmonauts failed to present manifestations of infectious pathology. This can be interpreted as evidence of efficacy of the general sanitary-hygienic and epidemic-control measures implemented at the preparatory stages and during the crews' work aboard Salyut-6 OS.

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UDC: 629.78:[574.685:579

DISTINCTIONS IN FORMATION OF MICROFLORA ON CONSTRUCTION MATERIALS USED IN HABITABLE PRESSURIZED COMPARTMENTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 18 Oct 83) pp 66-69

[Article by A. N. Viktorov and N. D. Novikova]

[English abstract from source] The composition of microbial and fungal associations on non-metal materials used in the interior design and equipment of enclosures was investigated when they were inhabited by men. It was found that the microorganisms formed on the structure materials were influenced by such factors as men and their specific microflora, accumulated water and dust, as well as the chemical structure of the polymers used.

[Text] At the present itme, it has been convincingly demonstrated that the properties of nonmetal materials can change under the influence of various microorganisms [2, 6]. When people are confined to pressurized compartments (PC), reproduction on materials of potentially pathogenic representatives of human autoflora and their migration into the air environment could worsen appreciably the sanitary and epidemiological situation. For this reason, it is important to investigate the ecological and hygienic patterns of formation of microbial and fungal associations on construction materials used in manned PC. We submit here the results of studies of the composition of microflora in the interior and equipment of PC while occupied by people.

Methods

In order to examine the nature of formation of microbial and fungal associations on nonmetal materials we used the washings method. Hottinger's agar with 5% human blood was used as the main nutrient medium. Sabouraud agar and Czapek's medium were used to demonstrate representatives of the fungal flora and starch-ammonia agar for demonstration of actinomycetes. Mannitol-salt agar was used to isolate staphylococci and Endo medium, for Gram-negative bacteria. The material under study was first heated at 80°C for 10 min, then inoculated on agar with polymyxin (200 units/100 mℓ/medium) in order to isolate and then assay Gram-positive sporulating bacteria. Microorganisms were identified according to their morphological tinctorial and biochemical features [4].

Results and Discussion

The results of our studies are indicative of significant fluctuation in extent of microbial contamination of various sections of PC surfaces. The most micro-organisms were discovered in areas with which people come in frequent contact (wall near sleeping places, area where meals are taken, region of automated control system, surfaces of hatches, etc.). A significant number of micro-organisms was also found in areas where a beneficial microclimate for microbial growth could develop due to operation of diverse equipment.

The species composition of microflora was represented to a significant extent by the constant inhabitants of the human upper respiratory tract and integument—epidermal staphylococci, corynebacteria and nonpathogenic neisseria. In addition, on the surfaces of the interior and equipment we demonstrated conditionally pathogenic microorganisms: Staphylococcus aureus, Proteus mirabilis, Enterobacter--Kelbsiella sp., Pseudomonas aeruginosa. We also periodically demonstrated Gram-negative bacteria of the genera Aeromonas, Acinetobacter, Moraxella and Gram-positive sporulating microorganisms of the genus Bacillus.

Composition of microflora formed on various types of polymers used in PC

Chemical basis of polymer	Composition of microflora	
	bacteria	fungi
Cellulose	Enterobacter, Staphylococcus	Penicillium
Protein	Staphylococcus, Aeromonas, Bacillus	Penicillium
Polyamide	Staphylococcus, Enterobacter, Bacillus, Corynebacterium, Neisseria	Penicillium, actinomycetes g.Streptomyces
Melamine-formaldehyde resin	Staphylococcus, Micrococcus, Enterobacter	Penicillium
Epoxy resin	Staphylococcus, Bacillus, Corynebacterium, Micrococcus	Penicillium
Polyvinylchloride	Enterobacter, Neisseria	Aspergillus
Polyethylene terephthalate	Enterobacter, Klebsiella, Micrococcus, Staphylococcus, Bacillus, Corynebacterium	Penicillium, Aspergillus
Polymethylmethacrylate	Acinetobacter, Enterobacter, Bacillus	Fusarium Mucor
Aromatic polyimide	Staphylococcus, Micrococcus	Penicillium
Polyisobutylene	Staphylococcus, Enterobacter, Citrobacter, Acinetobacter, Bacillus	Aspergillus, Penicillium, Rhizopus, Cladosporium, actinomyc., g.Streptomyces
Polystyrene	Bacillus	Penicillium
Trifluorochloroethylene	periodic Pseudomonas	periodic Penicillium
Mixed materials based on polyethylene terephthalate, polyamide and polyvinylchloride	Staphylococcus, Aeromonas, Moraxella, Enterobacter	Penicillium, Fusarium, Aspergillus

Micromycetes constituted a significant share of the biocenoses on nonmetal materials in the PC. The maximum number of fungal spores was found in areas

where there was a possibility of accumulation of moisture. The latter is very important. According to data of U. S. specialists [7], there is a possibility of microbiological destruction of construction materials used in manned PC, including manned spacecraft.

The species composition of microflora of nonmetal materials used in PC was notable for considerable diversity (see Table). On most surfaces, we found Penicillium (13 species) and Aspergillus (6 species) fungi. In addition, we periodically detected representatives of the genera Mucor, Fusarium, Rhizopus, Cladosporium and actinomycetes of the genus Streptomyces.

Fungi isolated from the surfaces of nonmetal materials included conditionally pathogenic species, Rhizopus oryzae, A. niger, A. oryzae and P. lanosum which, according to data in the literature [3, 5], can elicit toxicoallergic diseases in man when immunological reactivity is low.

It should also be noted that most of the identified species of fungi are active producers of enzymes and organic acids. This applies primarily to representatives of A. niger, A. oryzae and P. chrysogenum species. This circumstance is considered quite significant, since the products of vital functions of microorganisms are an important factor in biodeterioration of polymer materials. There may be various chemical reactions in polymers, which lead to change in their properties, due to enzymes secreted by fungi [1]. In turn, organic acids can also affect plastic like an aggressive medium and, being an incomplete product of oxidation of carbohydrates, they can be used by other microorganism species as a source of nutrient carbon.

The obtained data are indicative of the possibility of formation on nonmetal materials of microorganisms and, first of all, fungi that are not representatives of human autoflora, which makes it necessary to investigate the routes of their entry into the PC habitat and develop measures to prevent this process.

There are grounds to assume that the chemical structure of a polymer has a substantial influence on the nature of formation of associations of microorganisms on surfaces in manned PC. Thus, the largest number of microorganisms was detected on materials that are based on cellulose and protein, i.e., natural biopolymers; the fewest bacteria and fungi were found on fluoroplastics (based on trifluorochloroethylene) and foam plastics (based on polystyrene).

The most diversified species composition of microorganisms was found on surfaces made of rubber (based on polyisobutylene), polyethylene terephthalates, as well as mixed materials (see Table). Fungi of the genus Mucor were found only on materials based on polymethylmethacrylate, fungi of the genus Rhizopus and bacteria of the genus Citrobacter, only on rubber surfaces, while bacteria of the genus Pseudomonas were found on fluoroplastic. At the same time, bacteria referable to the genera Bacillus, Enterobacter and fungi of the genus Penicillium were encountered on most of the examined materials.

Our findings are indicative of the need to investigate the ecological and hygienic patterns of formation of microbial and fungal associations on nonmetal materials used in pressurized compartments in order to elaborate scientifically validated

recommendations to protect them and solve problems of normalization of the sanitary-microbiological status of PC environments.

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UDC: 629.78:[574.685:582.26

COMPOSITION AND DYNAMICS OF BACTERIOCENOSIS ASSOCIATED WITH ALGAE IN HUMAN LIFE-SUPPORT SYSTEMS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 31 Aug 83) pp 69-74

[Article by Ye. M. Kondrat'yeva]

[English abstract from source] The species and group composition as well as the number of bacteria concomitant with algae in the course of their continuous cultivation on a mineral medium as a self-contained system and as part of the biological life-support system were investigated. The major components of urine were passed to the reactor after its premineralization in a special unit. The experiments were carried out for 37 to 51 days. Under such cultivation conditions the number and generic composition of the algal microflora were stable. The common gas line between the algal reactors, units for urine microbiological mineralization and the manned module facilitated the generation of new bacterial groups which were, however, unable to develop in actively growing algal cultures and therefore disappeared rapidly. This indicates that the algal-bacterial cenosis within a biological life-support system has signs of a self-regulating system.

[Text] One of the substantial achievements in the area of building biological life-support systems (BLSS) for man on the basis of biological circulation of matter was the development of functional models of systems of biological regeneration of the atmosphere, water and, in part, food, with use of photosynthesis of unicellular algae. The photosynthetic element in such a system model was represented by a biocenosis of algae and concomitant microflora.

New opportunities appeared to investigate the question of microflora associated with algae thanks to development of the method of continuous cultivation of algae with recirculation of nutrient medium [6] in a closed air system. In this case, algae are the only source of soluble organic matter in the medium and accidental penetration of bacteria from the outside is reduced to a minimum. It was shown that, under such conditions, correlations are established between algae and bacteria, where accumulation of metabolites is compensated by the mineralizing activity of heterotrophic microorganisms, i.e., a biocenosis is formed with relatively closed trophic relations.

The dynamics of microflora population in an algal suspension during continuous cultivation with recirculation of medium are the same as the dynamics of quantity of extracellular organic matter. Stabilization of both these parameters in the course of an experiment occurs on the 15th-16th day of cultivation, after a transitionaly period that corresponds to the period of formation of a stable bacteriocenosis [3, 10].

With use of a continuous closed system of algal culture as the photosynthetic element in human BLSS models of diverse composition, the problem arises of possible exchange of microflora among elements of the system that has a common atmosphere, which could lead to disruption of established microbiocenosis in the algal reactor. This, in turn, could lead to change in functional characteristics of algae and impairment of their stability during system operation.

There are data in the literature pertaining to investigation of quantity and species composition of microflora developing in an an algal suspension when it is used as part of a BLSS [7, 8]. It was shown that, under such conditions, there is rather active exchange of microflora between elements, which leads to increase in diversity of microorganisms, with concurrent significant decline in their number and deterioration of mineralization of metabolites of algae in culture [2].

However, these findings were made when algae were cultivated in a system using unadulterated urine, which was added directly to the algal suspension and thus was an additional source of organic matter. This could not help but affect the composition of the bacteriocenosis in the algal suspension, which inevitably reflected transitory processes related to periodic addition of urine.

Our objective here was to investigate the composition and stability of the bacteriocenosis associated with algae when the latter were cultivated continuously on mineral medium as part of a model of a human BLSS, where they regenerated the atmosphere and water. The basic components of urine (nitrogen, water, carbon dioxide) were fed into the algal reactor only after mineralization in a special unit.

Methods

The system model we studied comprised, in addition to man, unicellular algae on the basis of Chlorella (C. pyrenoidosa, strain Sp-K), a unit for biological mineralization of urine, as well as units for evaporation of urine, drying of biomass and solid human waste [13]. The system's air volume constituted 4.5 m^3. Algae were cultivated in a continuous mode with recirculation of nutrient medium at optimum parameters of temperature, concentration of carbon dioxide and oxygen, minerals and medium pH. Balanced nutrient media, which contained nitrogen recovered upon mineralization of urine, were used as nutrition for algae [5].

Examination of concomitant microflora began after the transitional period (adaptation of algal culture to recirculation of medium). The algae element was connected to the closed system with man 11-26 days after the reactor reached nominal output. This enabled us to investigate the number and composition of microflora, first with algae being cultivated independently, then as part of

the system with man in the same experiment. We conducted 2 experiments lasting 37 and 51 days.

We determined the total number of bacteria by the direct count method in Perfil'yev capillaries [9]. We used two nutrient media for isolation of heterotrophic bacteria, beef-extract agar (BEA) and a medium with chlorella cell decoction. Conventional methods [11, 14, 16] were used to isolate other physiological groups of bacteria and identify their species. The results were submitted to statistical processing [1] and are submitted in the form of mean values, their standard deviations and coefficients of variation.

Results and Discussion

Table 1 lists mean values for total number of bacteria associated with algae, as well as number of groups studied when algae were cultivated independently and as part of the BLSS. The total number of bacteria in the suspension was in the range of 252-292 million cells/mℓ suspension, and it did not depend on the mode of cultivation of algae. A maximum coefficient of variation was found for self-contained cultivation, and it reached 27%. When the reactor operated as part of the system, the coefficient was lower, constituting 18%. We had demonstrated previously [3] about the same figures for total number of bacteria associated with algae when they were cultivated in the self-contained mode, continuously, with recirculation of nutrient medium.

Table 1. Number of bacteria associated with algae when cultivated continuously, separately and as part of BLSS

Experiment No	Cultivation conditions	Period, days	Algal output, g/ℓ/day	Bacteria: total, millions/mℓ	heterotrophs on BEA, millions/mℓ	heterotrophs broth medium, millions/mℓ	denitrifiers, millions/mℓ	sporul., thous/mℓ
1	Self-contained	11	7,3±1,3 (14) n=10	292±80 (27) n=7	36±9 (24) n=6	37±11 (30) n=6	1,7±0,5 (30) n=6	0,7±0,1 (14) n=5
	In BLSS	26	8,9±0,7 (8) n=14	252±52 (20) n=18	35±8 (24) n=8	33±8 (22) n=8	2,7±0,9 (33) n=5	10.2±3,1 (33) n=6
2	Self-contained	25	7,2±0,5 (7) n=18	265±70 (26) n=18	53±19 (36) n=11	71±23 (33) n=11	1,3±0,4 (31) n=6	0,7±0,05 (7) n=6
	In BLSS	26	8,5±1,0 (12) n=14	278±46 (18) n=18	26±6 (21) n=11	38±14 (37) n=11	2,5±0,5 (20) n=10	18.3±4,4 (23) n=10

Note: Coefficient of variation is given in parentheses, n--number of cases

Figure 1 illustrates the dynamics of total number of bacteria as compared to productivity of algae (in one of the experiments). The figure shows that total number of bacteria virtually failed to exceed 300 million cells/mℓ throughout the period of the study, and it was the most stable in the closing period. The main parameter of the algal culture, its productivity, was stable throughout the experiment, both during self-contained cultivation and after connection into the same gas and water system with man. Hence, it

can be concluded that other elements of the system do not influence the total quantity of microflora concomitant with algae.

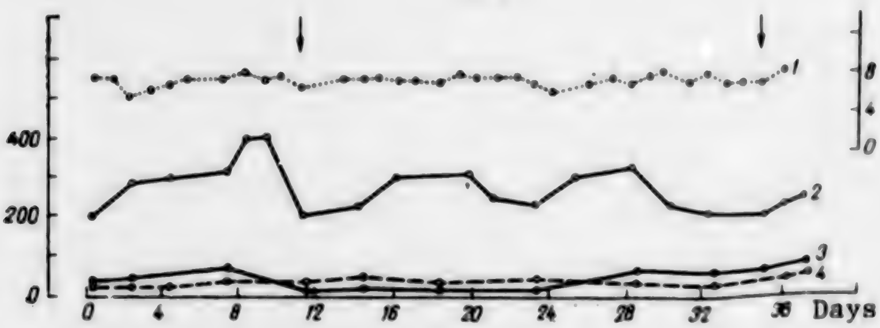

Figure 1. Dynamics of quantity of bacteria during long-term cultivation of algae. X-axis, day of study; y-axis, left--number of bacteria, right--productivity. Arrows show period of cultivation as part of human BLSS

1) algal productivity (g/ℓ/day)
2) total number of bacteria (million/mℓ)
3) number of heterotrophic bacteria on BEA (million/mℓ)
4) number of heterotrophic bacteria on medium with broth (million/mℓ)

In addition to total number of bacteria associated with chlorella when cultivated as part of the system, we also examined the quantity of bacteria referable to some physiological groups making up the microflora.

A significant part of the algal microflora consisted of heterotrophic bacteria isolated on BEA and in medium with algal cell broth (see Table 1). The main substrate for them are metabolites secreted by algae in the course of their vital functions. There were 26 to 53 million bacterial cells per milliliter suspension on BEA and 33-71 million cells/mℓ on medium with algal cell broth. Addition of the algal culture into the closed system including man and a mineralization element did not affect the number or dynamics of heterotrophic bacteria (see Figure 1).

The group of heterotrophic bacteria also includes spore-bearing bacteria, which are indicators of unfavorable cultivation conditions. The number of free bacterial spores, which constituted only 700/mℓ under self-contained cultivation conditions, rose to 18,000/mℓ after being included in closed system.

Denitrifying bacteria constituted a rather large group. Their number reached 2.7 million cells/mℓ. We failed to demonstrate nitrifiers in the algal culture.

In the case of self-contained cultivation, we found no bacteria in the suspension that destroyed cellulose. They appeared only after algae were included in the system, and their number gradually increased in the course of the experiment from 0 to 1000/mℓ. Activation of bacteria in this group, which was demonstrated starting on about the 15th-18th day of continuous cultivation and gradually

increased in the course of the experiment, was apparently related to accumulation of a significant amount of organic matter (of the cellulose type) that is difficult to break down, which is present in the algal suspension. It can be assumed that in longer term continuous cultures these bacteria will play one of the leading roles in removing metabolites from algal culture medium.

Table 2.
Dynamics of bacteria reaching algal culture from different parts of system during continuous cultivation under different conditions

Cultivation conditions	Day of experim.	E. coli bacteria, thous/mℓ	Urobacteria, thous/mℓ	Human automicroflora, million/mℓ
Self-contain	0	—	—	8 ± 0.7
	5	—	—	9 ± 0.8
	11	—	—	6 ± 0.5
In BLSS	14	—	—	13 ± 1.1
	18	70 ± 3.3	6 ± 0.4	31 ± 4.5
	23	10 ± 1.4	-	53 ± 6.0
	28	80 ± 4.4	6 ± 0.3	42 ± 5.5
	35	—	2 ± 0.2	22 ± 3.3
	37	—	—	10 ± 1.8

Note: Dash shows no bacteria were found.

Microscopic fungi were detected in the algal suspension only periodically and in small quantity (from 5 to 60 cells/mℓ). Their appearance in the algal culture was related to start of cultivation and times of inclusion of algae in the increasingly complex system with man and mineralization unit.

It was established that uniting the algal reactors through common gas and water systems with the cabin occupied by man and the unit for microbiological mineralization of urine causes appearance of new groups of bacteria which were absent during self-contained cultivation (Table 2).

Periodically, bacteria of the E. coli group appeared in the suspension of algae; they are an indicator of fecal contamination. After closing the system, their number reached 80,000/mℓ on some days.

Cabin air also revealed a large number of bacteria that are permanent inhabitants of human mucous membranes of the upper respiratory tract and integumental tissues. These bacteria are representatives of human automicroflora. Under self-contained cultivation conditions, their number did not exceed 10 million cells/mℓ, but after closing the system the number of bacteria of this group increased and fluctuated over a rather wide range in the course of the experiment, up to 53 million cells/mℓ. Such fluctuations are related to the constant migration of bacteria from the pressurized cabin in air, which is bubbled through the algal suspension, which caused bacteria to be removed from cabin air and its purification. The number of bacteria in cabin air in the case of a closed system did not exceed 5000 cells/ℓ air [12].

Urobacteria were not isolated from the algal culture when it was cultivated independently, and were periodically demonstrable after adding man to the system; their number did not exceed 6000 cells/mℓ.

Irregular isolation of bacteria referable to the above-mentioned groups in the algal suspension and absence of increase in their number in the course of a long-term experiment indicate that these groups of bacteria are incapable of developing in actively growing cultures of algae, and this is also confirmed by data in the literature [4, 15].

The bacteriocenoses of chlorella were represented by bacteria referable to three systematic groups: 1) Gram-negative aerobic bacilli (genera Pseudomonas, Achromobacter, Agrobacterium); 2) Gram-negative facultative anaerobic bacilli (genus Flavobacterium), and 3) corynebacteria (genera Arthrobacter, Corynebacterium, Mycobacterium, Microbacterium) (Figure 2).

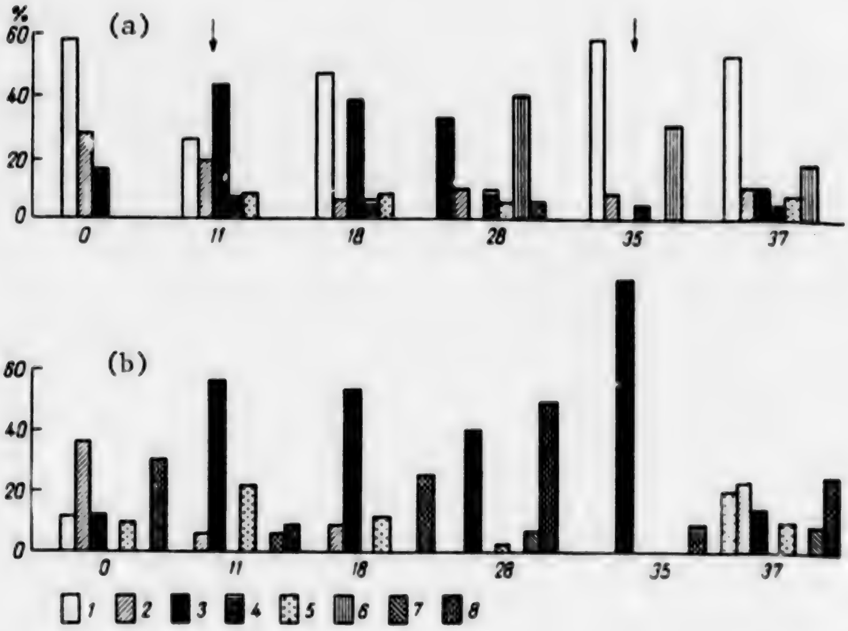

Figure 2. Share of different bacterial genera (%) when isolated on BEA (a) and medium with broth (b) during long-term cultivation of algae. X-axis, day of study; y-axis, percentage of bacteria genera

1) Pseudomonas
2) Flavobacterium
3) Arthrobacter
4) Achromobacter
5) Corynebacterium
6) Agrobacterium
7) Microbacterium
8) Mycobacterium

When chlorella was cultivated by itself, the prevailing group of bacteria demonstrable on BEA included, in addition to bacteria of the genus Pseudomonas (Ps. anebiqua, Ps. stutzeri), microorganisms of the genera Arthrobacter (A. globiformis, strain 1) and Flavobacterium (Fl. rigense, Fl. aquatile). The quantity of bacteria of these two genera diminished in the BLSS. On the other hand, Agrobacterium (A. radiobacter) bacteria, which were not present under self-contained conditions, appeared in significant quantity when the chlorella culture was part of the system and, along with Pseudomonas bacteria, made up the prevailing group of microflora.

Bacteria referable to the group of Gram-negative aerobes were virtually not demonstrable on medium with broth. In this case, microorganisms referable to the corynebacteria group were represented the most extensively, primarily Arthrobacter (A. globiformis, strain 1) and Corynebacterium (C. luteum) in

the self-contained cultures and A. globiformis, strain 2 in the closed system. Use of medium with broth made it possible to isolate bacteria which were not demonstrable at all on BEA--bacteria of the genus Mycobacterium (M. phlei and M. albume), which constituted a substantial part of the microflora both in the case of self-contained cultures and as part of a closed system with man.

Consequently, the bacteriocenosis of chlorella was represented by the same bacterial genera with both independent cultivation of algae and as part of the BLSS, although there was some change in proportion of representatives of different genera when algae were cultivated under different conditions.

Thus, in continuous cultures of chlorella with recirculation of nutrient medium both the number and generic composition of concomitant microflora were found to be stable. Hence, recirculation of nutrient medium is a technological procedure that provides conditions for formation of an algo-bacterial cenosis that functions with stability, not only under self-contained cultivation conditions, but as part of BLSS models where algae served as the photosynthetic element. The dynamic resistance of concomitant microflora to appearance of microorganisms from adjacent functional units demonstrated in our tests indicates that the algo-bacterial cenosis as part of a BLSS has elements of a self-regulating system.

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UDC: 629.78:574.685]:613.32:[546.32+546.33

EXPERIMENTAL VALIDATION OF ALLOWABLE CONCENTRATIONS OF SODIUM AND POTASSIUM IN RECYCLED DRINKING WATER

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 4 Apr 83) pp 74-78

[Article by V. A. Kondratyuk]

[English abstract from source] White noninbred rats were used to study the effect of reclaimed potable water containing 25-100 mg/ℓ sodium and 2.5-10 mg/ℓ potassium. The results show that consumption of water containing 50 mg/ℓ sodium and/or 5 mg/ℓ potassium disturbs their balance in the body. It is recommended to use water that contains 35 mg/ℓ sodium and 4.0 mg/ℓ potassium as a maximum, and 5.7 mg/ℓ sodium and 0.6 mg/ℓ potassium as a minimum

[Text] Sodium and potassium are essential elements for man. A very specific balance of sodium, potassium and fluid is required for normal metabolism [1]. The main sources of these elements are foods, and no more than 10% of the daily requirement is taken with drinking water.

Recently, a close link has been found between sodium level in drinking water and hypertension in its consumers. The opinion has been voiced that sodium concentration in water should not exceed 20 mg/ℓ [3, 13].

Physiologically adequate potable water is required in sufficient amounts during long-term spaceflights, exploration of desert and semidesert parts of our planet. Yet the water recovered by desalination and reclamation has no mineral salts, including sodium and potassium ions [11]. It is necessary to provide for this category of water, not only the minimum required but maximum allowed levels of the elements in question.

Methods

A six-month experiment was performed with 190 white male mongrel rats initially weighing 120-140 g, which were kept under vivarium conditions on the usual diet and differed only in quality of water they drank. The control (1st) group of animals was given dechlorinated tap water of the hydrocarbonate-calcium type containing 24-33 mg/ℓ sodium, 3.2-4 mg/ℓ potassium with total mineral content of about 500 mg/ℓ. The water for experimental groups was prepared on the

basis of recycled water which was then conditioned. For this purpose we used ion exchange resins (KU-2-12 pch, AV-17-8 pch;* PAU, MP-16, SP-6) with a high hygienic rating [4, 9]. The quality of the potable water complied with the specifications of GOST 2874-73 (see Table). The 2d group of animals was given recycled water, the 3d water with 100 mg/ℓ sodium, the 4th water with 10 mg/ℓ potassium and the rest water containing sodium and potassium: 5th group, 100.0 and 10 mg/ℓ, respectively; 6th group, 75.0 and 7.5 mg/ℓ; 7th, 50.0 and 5.0 mg/ℓ and 8th, 25.0 and 2.5 mg/ℓ. The water was offered to animals from automatic dispensers.

Physicochemical properties of recycled potable water

Parameter	Measurement unit	Quantitative expression
Odor	Grade	0
Taste	"	0
Transparency	Centimeter	30
Color	--	Colorless
pH	--	7.3
General hardness	Milligram-equivalent/ℓ	1.0-1.2
Calcium	Milligram/ℓ	14.0-16.0
Magnesium	"	3.6-5.4
Sodium	"	--
Potassium	"	--
Chlorides	"	11.0-16.0
Sulfates	"	18.0-24.0
Alkalinity	"	30.5-38.0
Dry residue		100

After 1, 3 and 6 experimental months, we analyzed the animals' peripheral blood, peroxidase and catalase activity [6, 7], level of chlorides of urea and creatinine in urine [5]. After euthanasia by decapitation, we determined the coefficients of weight of viscera (liver, kidneys, adrenals and stomach), assayed ascorbic acid, sodium and potassium in them [8], and performed pathomorphological examinations. The data were processed by a statistical method and evaluated according to Student's criterion.

Results and Discussion

Constant monitoring of the animals' general condition, behavior, water intake and weight failed to reveal differences between control and experimental groups.

Intake of water containing 50 to 100 mg/ℓ sodium and 5 to 10 mg/ℓ potassium (either separately or together) elicited, already 1 month from the start of the experiment, a statistically reliable increase in red cell count to $(6.4\pm0.4)\cdot10^{12}$-$(7.6\pm0.5)\cdot10^{12}$/ℓ, versus $(4.4\pm0.2)\cdot10^{12}$/ℓ in the control,

*Translator's note: pch could refer to quality--maximum purity.

and thrombocytes, and decrease in leukocytes from $(11.6 \pm 0.4) \cdot 10^9/\ell$ in the control to $(9.7 \pm 0.1) \cdot 10^9/\ell$ in the experiment, as well as blood color index and hemoglobin content per erythrocyte (from 35.2 to 19.8 pg). We found no reliable differences between groups with regard to blood formula.

Judging by blood catalase and peroxidase content, intake of water with different concentrations of sodium and potassium affected activity of redox processes. There was a statistically r liable decline of blood peroxidase (from 226 ± 6.0 to 190.6 ± 7.0 mmol/ℓ/h) 3 months after the start of the experiment in animals that drank water with 50 mg/ℓ sodium and 5 mg/ℓ or more potassium.

Fluid-electrolyte metabolism could be evaluated according to renal function. Chloride concentration was related to sodium and potassium content of drinking water. High intake of these minerals led to increase in urea (from 455.8 ± 39.3 to 795.0 ± 45.2 mmol/ℓ) and creatinine (from 13.5 ± 1.1 to 17.0 ± 0.9 mmol/ℓ) content of urine, which was apparently related to functional impairment of the endocrine system and, first of all, the adrenals.

According to data in the literature [12], the coefficients of organ weight are rather informative integral indicators of physical condition. Stomach weight is the most sensitive to sodium and potassium content: with 100 and 75 mg/ℓ sodium and 10 and 7.5 mg/ℓ potassium throughout the experiment it declined. Thus, while the coefficient of stomach mass constituted 0.96 ± 0.05-1.05 ± 0.04 g/100 g body weight in the control, it was 0.76 ± 0.03-0.87 ± 0.02 g/100 g body weight in the 7th group. By the end of the experiment the difference was also reliable in the 2d group. There were statistically significant differences between coefficients of heart mass in the 3d and 4th groups.

Intake of water with sodium and potassium, separately or together, in amounts of 75-100 and 7.5-10 mg/ℓ, respectively, elicited a statistically reliable incrase in adrenal ascorbic acid content. Throughout the experiment, ascorbic acid level was 14.1-14.5 mmol/kg in control rats and 18.2-22.4 mmol/kg in experimental groups. Starting with the 3d month of observation, we observed statistically reliable increase as well in the liver of animals in the 2d-6th groups. In renal tissue, there was a statistically reliable increase in ascorbic acid only when ingesting water with 10 mg/ℓ potassium.

Investigation of the effect of recycled drinking water on mineral metabolism in tissues of experimental animals revealed a correlation, though not always significant, between amount of sodium in water and in tissue, particularly skeletal muscles. Conversely, presence of potassium in drinking water elicited some decline in sodium content of skeletal muscles. With intake of both elements together in water, there was some increase in sodium content of muscles, including the myocardium.

We also examined mineral metabolism in the upper gastrointestinal tract. Sodium content of the wall of the stomach and duodenum did not differ with intake of recycled water throughout the experiment from the level in the control group. With increase in sodium content of water there was accumulation thereof in organs, but the difference was statistically unreliable.

Potassium content of gastric and duodenal tissue with intake of recycled water also failed to differ from the control. With increase in sodium and potassium

in drinking water there was accumulation of potassium in organs. This pattern became clearly established in the 3d month of the experiment. No substantial difference between control and experimental groups was demonstrable with intake of water containing less than 7.5 mg/ℓ potassium.

The liver and kidneys are the main organs that control mineral metabolism in the body. One month after the start of the experiment there was little change in sodium content of the liver of experimental groups. Thereafter (3 and 6 months after the start of the experiment) there was an increase in sodium content of the liver, and it was closely related to its concentration in the drinking water. Minimal levels were demonstrable in this organ in animals that consumed water containing only potassium (87.04 ± 4.1-118.3 ± 8.3 mmol/kg). With intake of water containing 100 mg/ℓ sodium there was a persistent and statistically reliable increase in its level in the organ (129.6 ± 7.0-158.3 ± 6.8 mmol/kg). A comparison of figures for the 3d and 4th groups failed to demonstrate distinct antagonism between sodium and potassium ions with regard to accumulation of sodium in hepatic tissues.

There was virtually no change in sodium content of renal tissue.

Potassium content of hepatic tissue was also directly related to its level in drinking water. Intake of desalinated water elicited a statistically reliable decrease in potassium content of hepatic tissue. In the 4th group of animals, which consumed water containing 10 mg/ℓ potassium, its concentration in the liver was at a maximum in comparison to other groups of animals. While its level in the liver of control group animals did not exceed 280.4 mmol/kg, it was at a level of 300 mmol/kg or higher when potassium concentration in water was in the range of 5-10 mg/ℓ. The difference in potassium content of the liver between experimental and control animals was insignificant ($P>0.2$) only with intake of water containing 2.5 mg/ℓ potassium and 25 mg/ℓ sodium.

A decrease in potassium concentration in drinking water leads to decrease in its level in renal tissues. Thus, in animals that consumed water with 10 mg/ℓ potassium its concentration in the kidneys was 399.3-413.9 mmol/kg; with 5.0 mg/ℓ potassium in water, it was 373.0-379.6 mmol/kg and with intake of recycled water it was 269.3-271.8 mmol/kg. Potassium content did not exceed 305 mmol/kg in the control group. The figures were virtually the same in the 8th group as in the control.

The proportion of sodium and potassium ions is an important indicator of mineral metabolism. This parameter changed insignificantly in the myocardium. It was lower than in other groups only in animals of the 4th group which took water without sodium. The liver reacted more than the heart to a change in quality of drinking water. This parameter was 1.5 times higher with intake of water containing 100 mg/ℓ sodium (3d group) than with intake of water containing only potassium. Presence of both elements in water led to its normalization.

Intake of water containing 10 mg/ℓ potassium elicited a decline of this parameter in tissues of the kidneys, stomach, duodenum and skeletal muscles. It was somewhat lower in renal tissue than in the control with intake of water containing only sodium, as well as sodium and potassium. It was somewhat higher than the control level with intake of recycled water.

Maintenance of stable physiological, vitally optimum concentrations of macroelements in interstitial fluid is a function of the body's hard frame. On the basis of the results of osteometry and analysis of chemical composition of bones of experimental animals, it was established that intake of water with elevated levels of sodium and potassium ions is instrumental in accelerating growth and intensifying mineralization of skeletal bones. Hypermineralization of spongy bone is caused by the organic component, as well as increased moisture of bones. Intake of recycled water (2d group) was associated with hypomineralization of bone.

Investigation of immunological reactivity revealed enhancement of complement utilization reaction in all experimental groups of animals. We also tested gonadotropic effects; however, we failed to demonstrate changes in morphology of gonads, motility, resistance or acid-resistance of spermatozoa.

Histological and histochemical studies of viscera of animals who consumed water with elevated levels of sodium and potassium revealed swelling of the mucosa of the stomach and small intestine, dissociation of hepatic trabeculae of hepatocytes, sites of hemorrhage and signs of plasmorrhagia in some places, insignificant enlargement of epithelium of convoluted tubules in the kidneys, depression of activity of succinate dehydrogenase and acid phosphatase.

Previous experiments with dogs and observations of humans [2] indicate that intake of water containing 500-700 mg/ℓ sodium chloride elicits early changes in secretory function of the stomach, level of diuresis and clearance, although these changes were adaptive, rather than pathological, in the opinion of the cited authors.

As can be seen from the submitted data, intake by white rats of recycled potable water containing 50 mg/ℓ sodium and 5 mg/ℓ potassium (either separately or together) impairs homeostasis in experimental animals. Using the method of probabilistic evaluation [10], one can recommend values of 35.0 mg/ℓ sodium and 4.0 mg/ℓ potassium as maximum allowable concentrations in recycled drinking water and 5.7 mg/ℓ sodium and 0.6 mg/ℓ potassium as the minimum required concentrations.

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UDC: 612.014.426

MAMMALIAN TISSUE SENSITIVITY TO LONG-TERM EXPOSURE TO HIGH-INTENSITY STATIONARY MAGNETIC FIELDS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 24 Aug 83) pp 78-81

[Article by G. V. Galaktionova, V. M. Mastryukova and A. D. Strzhizhovskiy]

[English abstract from source] The retinal epithelium, bo e marrow and spermatogenic epithelium of mice exposed for 30 days to constant magnetic fields of 1.6 T were examined cytologically. During and after exposure the retinal and bone marrow epithelium showed no biologically significant deviations from normal. The mitotic changes were of small amplitude and insufficient to cause cell unbalance. No chromosome aberrations or degenerative changes in the cells were seen. In the spermatogenic epithelium the exposure to a constant magnetic field produced a destruction of mature cell elements. Due to this the total amount of spermatogenic cells was significantly lower during and immediately after exposure.

[Text] The intensi e use of magnetic fields for scientific and engineering purposes has made it quite important to determine whether adaptation to them is possible. As a result there was an increase in interest in the results of studying reactions of the body to long-term exposure to stationary magnetic fields (SMF). The data in the literature on this score include some rather detailed information about peripheral blood of experimental animals; however, other mammalian tissues were studied only at relatively low field intensities [3]. Yet it is necessary to conduct experiments with strong fields to assess the body's compensatory capacities and define the range of tolerance to magnetic fields. We submit here the results of cytological analysis of bone marrow, corneal epithelium and spermatogenic epithelium of mice submitted to high-intensify SMF for many days.

Methods

Experiments were conducted using a water-cooled direct current SP-57A electromagnet with flat parallel pole tips 900 mm in diameter and 100-mm space between them. Current was supplied to the electromagnet from a P-III converter placed in a special room apart f n the electromagnet. In the center of the electromagnet's active zone SMF induction constituted 1.6 T; it remained

virtually constant in an area 760 mm in diameter and dropped to 1.3 T at the edgs of the pole tips. The SMF was vertical and there was no induction pulsation.

Experimental male F(CBA×C57Bl) mice weighing 18-20 g were placed in the active zone of the magnet in aired plexiglas containers and exposed to SMF for 30 days. Control animals were kept in identical containers placed in a phantom of the electromagnetic made of duralumin.

Experimental mice were decapitated concurrently with control animals at different stages of exposure to SMF and at different postexposure times; we took samples of bone marrow, corneal and spermatogenic epithelium. In the bone marrow and corneal epithelium samples we determined the number of cells, mitotic index and incidence of aberrant mitoses at the anaphase stage (bridges and acentric fragments). Quantity of marrow cells was determined from their number in the femur [6] and the mitotic index and aberrant mitoses on smears fixed in methyl alcohol and stained with methylene blue. Total corneal preparations were stained with hematoxylin according to Carazzi and in the two bottom reproductive layers of cells we counted cells per standard microscope field of vision, the mitotic index and incidence of aberrant mitoses. We prepared a suspension of testes, submitted it to vital staining with gentian violet and in a Goryayev chamber we counted the total number of spermatogenic epithelium cells and spectrum of their distribution according to types (spermatogonia, spermatocytes, spermatids, spermatozoa) using the method in [2]. We used a total of 718 animals in the experiments.

Results and Discussion

Table 1 and Figure 1 give the results of cytological analysis of tissues at different stages of SMF exposure. The corneal mitotic index was somewhat high on the 1st day, declined for the next 6 days, then gradually reverted to normal and remained at the control level to the end of the exposure period. In spite of this, the number of corneal epithelial cells remained highly stable throughout the period of SMF exposure. The mitotic index and number of bone marrow cells underwent phasic changes of low amplitude. We failed to demonstrate chromosomal aberrations or degenerative changes in the cells of the examined tissues.

Since we failed to demonstrate clearcut changes in the same direction in most of the criteria considered (with the exception of the mitotic index of the corneal epithelium), we used values averaged for the entire period of exposure to SMF as characteristics of the magnetobiological reaction. This approach enables us to offer an integral evaluation of the effect as a whole and determine the extent of change in equilibrated state of the tissues studied. Averaged values for the exposure period for number of cells of corneal epithelium, mitotic index and number of bone marrow cells constituted 100.8±0.6, 103.2±3.1 and 99.3±1.7%, respectively, of their normal values. Thus, it was established that exposure to SMF does not elicit a change in equilibrium of corneal epithelium and bone marrow.

SMF elicited a more marked reaction in the testes. During exposure, there were phasic changes in number of cells at different stages of development and

Table 1. Changes in mitotic index and number of cells in corneal epithelium and bone marrow of mice submitted to long-term SMF exposure

Parameter	Tissue	SMF exposure time, days						
		1	4	7	10	15	22	30
Mitotic index, % of control	Corneal epithelium	122,0±7,5	88,2±5,9	76,4±5,0	89,8±5,2	107,0±7,2	107,5±6,1	100,4±10,4
	Bone marrow	92,4±5,2	108,4±9,6	95,4±10,2	110,3±6,4	121,0±6,4	105,4±7,2	89,7±11,2
Cells, % of control	Corneal epithelium	100,8±1,3	99,5±1,0	100,8±1,6	102,2±0,9	101,6±1,1	100,3±1,3	100,2±2,1
	Bone marrow	97,7±3,8	87,6±3,5	110,1±7,7	104,3±3,3	102,0±2,9	104,7±4,1	88,7±5,2

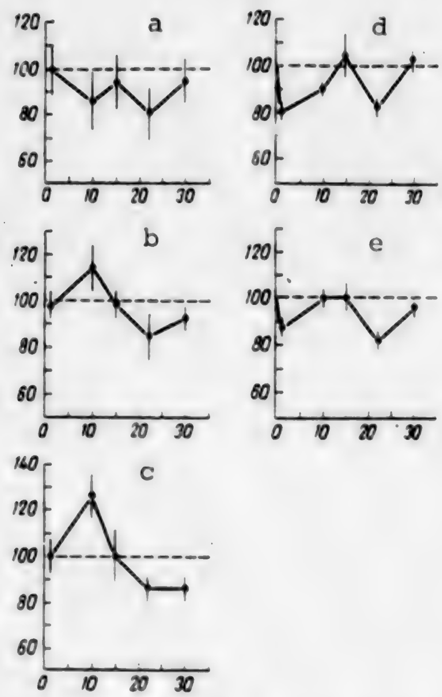

Figure 1.
Changes in cell composition of mouse spermatogenic epithelium during long-term exposure to SMF; x-axis, time after start of exposure (days); y-axis, number of cells of indicated type (% of control). Here and in Figure 2:
a) spermatogonia
b) spermatocytes
c) spermatids
d) spermatozoa
e) total number of cells in spermatogenic epithelium

total number of spermatogenic epithelium cells, the amplitude of which reached 20-25% of the control level. Averaged values for the entire period of exposure to SMF were as follows, in relation to normal levels: 91.8±5.1% for number of spermatogonia, 97.2±3.5% for spermatocytes, 99.6±3.9% for spermatids, 91.8±2.4% for spermatozoa and 93.2±1.8% for total number of spermatogenic epithelium cells.

The low values for magnetobiological effects in question could be due to either the low sensitivity of the tissues studied or their effective adaptation to long-term SMF. Judging from data in the literature, the latter assumption is more probable. As we know [3], brief exposure to SMF elicits inhibition of mitotic activity in the corneal epithelium and bone marrow; however, as exposure time increases depression of mitotic activity diminishes and, in some cases, it is even activated. Inhibition of cell division has been observed in the spermatogenic epithelium under the effect of short term SMF [4].

The results of cytological analysis of tissues at different stages after 15- and 30-day exposure to SMF are listed in Table 2 and Figure 2. We observed fluctuation of mitotic activity in the corneal epithelium and bone marrow; however, it did not lead to substantial changes in number of cells: it remained virtually the same in the corneal epithelium and changed by no more than 10-15% in bone marrow. Unlike these tissues, the spermatogenic epithelium

Table 2. Changes in mitotic index and number of cells in corneal epithelium and bone marrow of mice after 15- and 30-day exposure to SMF

Parameter	Tissue	Exposure time, d	Postexposure days				
			base	1	2	3	6
Mitotic index, % of control	Corneal epithelium	15	107.0±7.2	102.9±11.5	104.9±7.8	127.9±10.3	143.1±15.7
		30	100.3±10.4	115.6±17.1	—	76.5±6.1	114.7±7.5
	Bone marrow	15	121.0±6.4	108.2±9.1	100.0±6.9	91.1±7.2	124.6±7.8
		30	89.7±11.2	116.4±6.8	—	109.8±3.4	88.3±3.8
Number of cells, % of control	Corneal epithelium	15	101.6±1.4	97.2±2.5	104.2±3.7	95.1±2.6	102.4±3.6
		30	100.2±2.1	100.6±2.2	—	103.2±2.2	101.0±1.3
	Bone marrow	15	102.0±2.9	95.6±3.3	96.0±3.3	99.2±3.2	93.0±5.6
		30	88.7±5.2	106.0±3.9	—	91.1±4.1	112.0±3.7

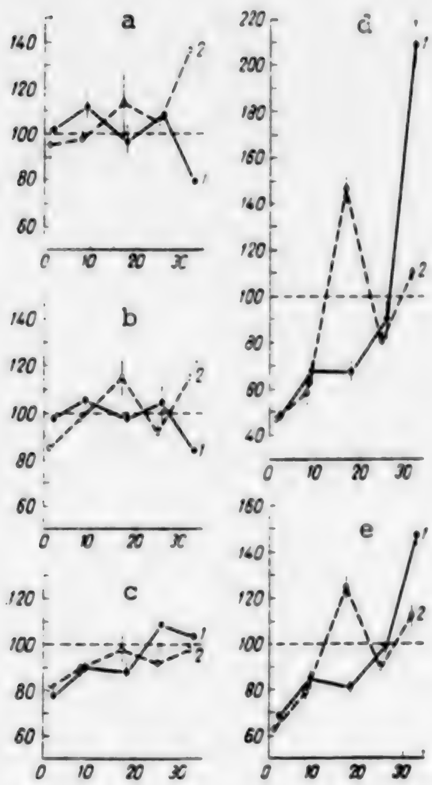

Figure 2.
Changes in cell composition of mouse spermatogenic epithelium after 15- and 30-day exposure to SMF; x-axis, time after SMF exposure (days), y-axis, number of cells of indicated type (% of control) 1, 2) 15- and 30-day exposure to SMF, respectively

revealed a decrease in total number of cells at the early post-SMF stages. In spite of the normal number of spermatogonia, which was indicative of their high proliferative activity, the number of mature spermatogenic cells was low. After this decline, the number of spermatogenic cells rose drastically and for a time exceeded normal values appreciably.

A comparison of findings for the corneal epithelium and bone marrow during exposure to SMF and after its discontinuation convinced us of the similarity of their adaptation to high-intensity SMF and readaptation to the normal geomagnetic field. One can arrive at an analogous conclusion from analysis of data in the literature [1, 5]. In experiments with thrombocytes and reticulocytes of mice exposed for 15-20 days to SMF of different intensities, a distinct readaptation reaction was demonstrated, similar in nature and magnitude to the changes in these cells during exposure.

The changes in condition of the spermatogenic epithelium were more marked after stopping SMF exposure than during exposure, unlike the changes that occurred in the corneal epithelium and bone marrow. The reason for this was intensification of destruction of mature spermatogenic cells due to the additional burden on tissue, which was already weakened by preceding exposure to SMF.

The low resistance of mature cells is a specific feature of the spermatogenic epithelium, which distinguishes it from other tissues of mammals. Because of it, the compensatory capacities of tissue as a whole are diminished, which warrants consideration of the testes as the critical organ in setting hygienic standards for long-term exposure to SMF.

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UDC: 617-089.583.29

ELECTROANESTHESIA AS A MEANS OF CONTROLLING COLD STRESS OF LOCAL HYPOTHERMIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 3 Feb 84) pp 81-85

[Article by L. L. Stazhadze, V. V. Sigayev, A. A. Titov, A. N. Romanov, L. G. Repenkova and S. I. Avdeyev]

[Text] Local hypothermia has gained wide use in clinical practice in the last two decades. Selective cooling of individual organs and parts of the body has made it possible to attenuate significantly adverse changes in the body and, consequently, enhance the efficacy of treating many serious diseases.

Considering the prospects of exploring extraterrestrial space, local hypothermia may expand significantly the existing capabilities of space medicine.

At the same time, it would be premature to consider the problem of adequate protection of the human body against forced (therapeutic) exposure to cold as having been solved. The physiological mechanisms at the basis of adaptation to low temperature conditions are still far from clear [1].

From the standpoint of space medicine, this problem is even more complicated because of the set of changes in homeostasis due to the effects of spaceflight factors, primarily weightlessness.

Significant difficulties are encountered, which are related primarily to the distinctions of the chief complaint, when producing craniocerebral hypothermia in the presence of cerebrocranial trauma are transgastric cooling of the pancreas in the presence of acute pancreatitis and assessing reactions to cold and extent to which drugs counteract them. This is apparently the explanation for the existing opinion that more attention should be given to the level of anesthesia than choice of anesthetic when producing local (in particular cerebrocranial) hypothermia [2].

As we know, electroanesthesia has virtually no toxic effect on parenchymatous organs. In this respect, it could be close to an ideal method of anesthesia.

We submit here some data on the feasibility of electroanesthesia as a means of controlling adverse reactions to local cooling of the stomach during anti-orthostatic hypokinesia, which simulates some of the effects of weightlessness.

Methods

These studies were conducted with the participation of 15 essentially healthy men (26 to 42 years of age) who had undergone special clinical screening. Before hypothermia, all of the subjects had spent 7 days on strict bedrest in antiorthostatic [head-down tilt] position (-8°). On the 8th day, gastric hypothermia was produced without altering the subjects' position (to prevent acute and progressive change in circulation).

Local cooling of the stomach was performed using an ALG-2 apparatus. After local anesthesia of the walls of the pharynx with 1% dicain solution, a double-lumen catheter with a thin latex rubber balloon was passed through the mouth into the stomach, and coolant at a temperature of about 0°C was circulated through the catheter. Concurrently, we monitored rectal temperature using a temperature-sensitive sensor. The stomach was cooled for 3 h.

Local hypothermia was produced under electroanesthesia in 9 cases (1st group); for this purpose, using an EA-301 apparatus, Limoge current was delivered through externally placed electrodes (mastoid processes and forehead) using a method developed at the Institute of Surgery imeni A. V. Vishnevskiy. We used high-frequency pulses modulated with low frequency and current amplitude reached 30 mA.

In the remaining 6 subjects (2d group), local hypothermia of the stomach was produced after premedication (1 mg atropine, 20 mg dimedrol, 20 mg promedol intramuscularly) and local anesthesia of the pharyngeal walls with 1% dicain.

During the tests, we recorded a polycardiogram, parameters of external respiration, determined acid-base status and blood gases, oxygen uptake, coagulogram, parameters of free-radical oxidation in erythrocytes and plasma.

Results and Discussion

During hypothermia, rectal temperature dropped by a mean of 1-1.5°C. We used heating pads when temperature dropped to 35°C.

Local cooling of the stomach was associated in the 2d group of subjects with subjective sensation of cold, appearance of marked muscular tremor and cyanosis of the nasolabial triangle. In the 1st group, the unpleasant sensations were milder. One of the subjects in this group had been submitted to similar 3-h local hypothermia 6 months prior to hypothermia under electroanesthesia, but that time it was after premedication similar to the premedical of the 2d group of subjects (without electroanesthesia). This subject also reported less temperature discomfort under electroanesthesia. In addition, his tremor was moderate, and there was no cyanosis of the integument.

In both groups of subjects, local gastric hypothermia was associated with some decline of cardiac output with increase in peripheral vascular resistance (Table 1). This decline of minute output was due to significant decline of stroke output, which was not compensated by an increase in heart rate. There was some worsening of myocardial contractility of the stress type (more so in the 2d group): the index of myocardial tension increased by a mean of 3% in the 1st group and by 6.2% in the 2d. Electrocardiographic parameters (size of waves and intervals) remained virtually unchanged.

Table 1. Parameters of central hemodynamics in the presence of local hypothermia

Parameter	HT with electroanesthes. (1st group)		HT with premedication (2d group)	
	before	after	before	after
CO, ℓ/min	4.6±0.44	4.1±0.28	4.9±0.49	4.1±0.31
SV, mℓ	74.0±0.75	59.0±0.61*	75.5±0.73	62.0±0.70*
CI, ℓ/min•m^2	2.4±0.27	2.2±0.21	2.5±0.26	2.15±0.17
IMW	3.1±0.32	2.9±0.25	3.4±0.30	2.85±0.26
TPR, dyne•s/cm^{-5}	1820±207.6	2114±218.4*	1736±224.8	1964±203.4*
ISI	84.5±1.97	85.4±1.74	80.3±2.36	80.3±1.59
IMT	25.6±1.23	26.8±1.33	30.6±1.35	32.5±1.37
T, s	0.104±0.0056	0.102±0.0057	0.117±0.0053	0.124±0.0064
A_s, s	0.050±0.0052	0.055±0.0054	0.051±0.0064	0.061±0.0053
I_c, s	0.054±0.0059	0.048±0.0051	0.066±0.0096	0.063±0.0053
E, s	0.301±0.061	0.282±0.0063	0.266±0.0064	0.256±0.0064
S_m, s	0.356±0.0083	0.329±0.0086	0.332±0.0096	0.319±0.0006

Key:

CO) cardiac output
SV) stroke volume
CI) cardiac index
IMW) index of minute work
TPR) total peripheral resistance
ISI) intrasystolic index
IMT) index of myocardial tension
T) period of cardiac contraction
A_s) asynchronous systole
I_c) isometric contraction
E) ejection period of left ventricle
S_m) mechanical systole

Note: Here and in Table 2, asterisk indicates $P<0.05$.
Here and in Tables 2, 3, 4: HT--hypothermia.

At maximum cooling, capillary and venous blood showed a tendency toward development of compensated metabolic acidosis, as well as some decline of oxygen tension. Upon termination of hypothermia these changes diminished, there was some increase in respiratory minute volume and oxygen uptake (Table 2). It should be noted that there were no changes after hypothermia under electroanesthesia in the direction of respiratory acidosis, as seen in the 2d group of subjects.

Changes in the blood-clotting system were insignificant and consisted merely of a tendency toward increase in clotting activity and decrease in anticoagulating system activity (Table 3).

In both groups of subjects, local gastric hypothermia led to 2-3-fold elevation of free-radical levels in red cell membranes (Table 4). At the same time, the levels of diene conjugates of blood plasma dropped on the average to one-fifth the former value with a tendency toward rise in triene and tetraene conjugates, as well as lipid levels. It is known that elevation of free-radical levels in biological membranes leads to drgradation of fatty acids, conformational changes in proteins, change in structural and functional state of membranes and, first of all, impairment of their permeability. The levels of free radicals is controlled by an enzymatic and nonenzymatic antioxidant system. The parameters we obtained for the dynamic correlation between these systems, which largely determines constitutional resistance to different factors, characterize in particular the body's resistance to cold.

Table 2. Parameters of external respiration during local hypothermia

Group of subjects	Time of examin.	pH	SB	BE	pCO_2	pO_2	MV	p_ACO_2	p_AO_2	Rusc	Oxygen uptake
1	Before HT	7,394±0,013	24,7±0,800	−0,3±0,90	44,9±6,38	80,5±3,19	6,4±0,86	36,3±1,69	105,3±5,40	5,0±0,40	219,9±25,3
	HT, 90 min	7,347±0,011*	22,3±0,39	2,7±0,57	42,7±2,84	71,5±3,55	6,5±0,84	36,2±1,18	105,5±0,59	5,1±0,80	206,8±24,7
	HT, 180 "	7,401±0,029	22,7±0,89	−2,2±1,20	36,6±4,39	78,3±5,45	7,3±1,26	33,6±1,76	105,8±3,24	5,3±0,42	278±40,7
2	Before HT	7,386±0,008	25,2±0,39	−0,2±0,68	43,8±2,26	79,6±2,12	6,1±0,83	38,8±1,69	102,4±2,48	4,9±0,42	230,3±33,5
	HT, 90 min	7,330±0,017	23,9±0,46	−2,8±0,67	41,2±2,37	72,3±3,14	6,3±1,43	39,6±2,12	103,6±1,17	5,2±0,93	182,7±36,4
	HT, 180 "	7,310±0,023*	23,1±0,54	−4,2±0,82	44,3±3,05	70,1±4,16	7,0±1,31	34,5±2,03	101,9±3,26	5,1±0,67	232,4±34,6

Note: Parameters of acid-base state were determined in capillary blood.

Table 3. Parameters of blood clotting during local hypothermia

Group of subjects	Time of examin.	Start, s	End, s	Duration, s	Start of retraction, s	Amplitude	
						maximum	minimum
1	Before HT	150,56±20,47	458,89±16,41	287,22±25,25	611,67±35,96	3,22±0,098	0,21±0,031
	HT, 90 min	131,11±19,09	433,33±18,76	302,78±20,14	690,56±36,81	3,06±0,27	0,19±0,056
	HT, 180 min	128,33±21,35	412,78±23,84	282,22±24,01	726,11±36,40	2,94±0,15	0,12±0,015
2	Before HT	144,47±28,34	448,39±19,21	304,44±23,60	625,73±36,14	3,33±0,084	0,24±0,036
	HT, 90 min	130,23±16,33	430,24±17,33	301,32±25,40	673,14±34,23	3,22±0,31	0,20±0,063
	HT, 180 min	125,42±22,27	419,13±13,42	292,23±24,7	710,12±32,12	3,24±0,33	0,14±0,021

Note: P>0.05 in all cases.

Table 4. Parameters of free-radical oxidation (FRO) during local hypothermia

Parameter	Specimen	1st group		2d group	
		before HT	180-min HT	before HT	180-min HT
Diene conjugates, optic units	Red cells	0,061±0,025	0,181±0,103*	0,067±0,025	0,051±0,017
	Plasma	1,140±1,522	0,225±0,133*	0,232±0,159	0,177±0,046
Triene conjugates, optic units	Red cells	0,021±0,002	0,076±0,031*	0,015±0,003	0,031±0,010*
	Plasma	0,115±0,062	0,123±0,066	0,046±0,009	0,187±0,117**
Tetraene conjugates, optic units	Red cells	0,023±0,015	0,042±0,017	0,008±0,003	0,025±0,004*
	Plasma	0,025±0,018	0,030±0,018	0,018±0,005	0,032±0,008*
End FRO products, optic units	Plasma	0,078±0,021	0,095±0,020	0,114±0,050	0,117±0,018
Total lipids, mg%	Plasma	686,7±58,8	820,0±495,6	591,7±94,6	547,2±135,9

* $P<0,05$.
** $P<0,01$.

After 90 min of local cooling, rectal temperature dropped by a mean of 1°C, oxygen uptake by 5-7%, while changes in acid-base status were in the direction of acidosis. In this period we observed drastic reduction in number of erythrocytes, 2,3-diphosphoglyceride (2,3-DPG) and increase in components of the adenyl system--ADP and ATP. After 3 h of hypothermia, 2,3-DPG level rose in the 1st group, but remained considerably lower than the base value. The levels of adenyl system fractions (ATP and ADP) dropped somewhat without, however, reaching base values. Fluctuations of inorganic phosphorus were insignificant. The decrease in concentration of 2,3-DPG and increase in adenyl system fractions are indicative of diminished intensity of tissular respiration. Under these conditions, electroanesthesia caused some improvement of the latter.

Thus, local gastric hypothermia for individuals with specific changes in homeostasis due to antiorthostatic hypokinesia did not lead to any clinically significant structural or functional changes.

The submitted results also indicate that electroanesthesia has some protective properties against cold stress. The effect of electroanesthesia was as good as premedication according to all of the recorded parameters, whereas the deviations of homeostatis that were recorded were not extreme and did not constitute an additional hazard by themselves. At the same time, it is necessary to indicate that electroanesthesia alone, in the form used at the present time, does not provide complete protection against cold factors. However, when combined with drug support it could be an alternative under appropriate conditions. The latter should very probably become the subject of future research.

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BRIEF REPORTS

UDC: 616.24-091-02:612.766.2]-092.9

MORPHOLOGICAL MANIFESTATIONS OF HEMODYNAMIC CHANGES IN LUNGS OF MONKEYS SUBMITTED TO ANTIORTHOSTATIC HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 17 Jan 83) pp 85-87

[Article by V. I. Yakovleva and G. S. Belkaniya]

[Text] Comprehensive material has been accumulated to date on investigation of the effects of long-term clinostatic and antiorthostatic hypokinesia (AOH) on man [1, 6, 7, 9, 11]. In particular, it was established that, under hypokinetic conditions and particularly AOH, there is redistribution of blood in the body, intensification of venous return of blood to the heart, which leads to plethora of the atria and vessels in the pulmonary circulatory system. Recently, works have been published concerning investigation of hemodynamics in the pulmonary circulation using different methods (radioisotope, rheographic, catheterization of vessels). With these methods it was shown that both short- [4, 8, 12] and long-term AOH [3, 5, 14] is associated with an increase in volume of circulating blood in the lungs. Since hemodynamics in monkeys are similar to man, it was interesting to examine the lungs of monkeys during AOH using histological and morphometric methods, particularly since such studies had not been conducted previously.

Methods

Experiments on male monkeys (Macaca rhesus) were performed at the Institute of Experimental Pathology and Therapy, USSR Academy of Medical Sciences (Sukhumi). A method of immobilizing animals in horizontal position (prone) on a special cot, which was specially developed for this purpose, was used to produce hypokinesia [13]. For 7 days, 3 monkeys were kept under horizontal hypokinetic conditions then changed for 12 days to antiorthostatic position at an angle of -6°. The other 2 monkeys were submitted only to AOH for 7 days in order to simulate the acute period of adaptation to weightlessness. The animals were sacrificed by intravenous injection of 10% hexenal solution in a dosage of 2-3 mℓ, depending on the animals' weight, which ranged from 3 to 4 kg in control and experimental monkeys before the experiment. None of the animals had reached puberty, and they ranged in age from 2.5 to 3 years. We examined the lungs of 3 control and 5 experimental monkeys. In order to preserve an amount of blood in the lungs close to the vital volume, after dissecting the chest we ligated the arteries and veins of both lungs in the portal region,

then cut the lungs off beyond the ligature, weighed them and fixed them whole in 10% solution of neutral formalin. After fixing, the lungs were cut lengthwise into 4 layers 1.5-2 cm thick. We took three tissues samples (from top, middle and lower regions) from each layer (one near the root, two in the middle and a subpleural one). In all, we examined 12 specimens from each lung. Thus, lung tissue was taken from all animals from the same segments at different distances from the root of the lung. The material was imbedded in paraffin. The preparations were stained with hematoxylin and eosin, according to Weigert, Van Gieson, we used a combined stain after Weigert with additional staining with iron hematoxylin and picrofuchsin and ran the Perls reaction. Morphometry of small arteries of the muscular type (on the level of respiratory first- and second-order bronchioles) of the system of the pulmonary artery was performed with an MOV-15 micrometer (the eyepiece gage had 18.75 μm graduations with a 40× objective). We measured 50 oval arteries from each monkey. We determined the following parameters: diameter of the artery within the external elastic tunic, lumen measurement, thickness of muscular layer between two elastic tunics. The cross section of the muscular tunic was calculated using the formula, $S = \pi m (d+m)$, where m is thickness of the media and d is diameter of the lumen. In addition, we determined Kernogen's index (ratio of thickness of media to diameter of lumen) which enables us to differentiate between dynamic changes in tonus and structural changes. The results were submitted to statistical processing by the method of Student.

Results and Discussion

Dissection of the lungs revealed marked plethora. Upon cutting lung tissue (after fixing it) we demonstrated dilatation and plethora of large veins and arteries in the portal region, in both experimental and control animals. In other parts of the lungs of control animals plethora was moderate, whereas in monkeys of both experimental groups there was marked vascular plethora even in regions of the lung farther from the hilus, and the vessels often contained dark blood clots.

Weighing revealed that the absolute mass of the lungs increased substantially in experimental groups, as compared to the control (by 29% with 7-day hypokinesia and 12-day AOH, by 19% with 7-day AOH).

Microscopy confirmed the presence of differences in degree and extensiveness of pulmonary plethora in experimental and control monkeys. In control animals it was particularly marked in the region of the radix and lower parts of the lung, whereas in experimental groups plethora was demonstrable in virtually all parts of the lungs.

Examination of vessels of different calibers revealed that large and medium-sized arteries and veins did not differ appreciably from the control in blood content, whereas small arteries (on the level of the terminal and respiratory bronchioles) were considerably more dilated and plethoric in experimental animals (particularly with 19-day hypokinesia). However, as was to be expected, most of the blood was deposited in capillaries and veins. Fine veins were drastically dilated in experimental monkeys and had the appearance of broad bands with lateral ramifications or large cavities. The tortuous and

dilated capillaries formed lacuna-like reservoirs filled with erythrocytes, in some areas they were in the form of clusters protruding into the alveolar lumen. Venous plethora was also demonstrated in the system of bronchial arteries.

In spite of the plehtora, there were no demonstrable morphological signs of stasis in the lungs in the form of edema, hemosiderophages or bronchial catarrh.

The impression was formed that, with 7-day hypokinesia and 12-day AOH, venous and capillary plethora was associated with appearance of signs of coarsening of the elastic shell of the lung. Distinct, tortuous and thickened fibers appeared in the alveolar walls; coarsening of the media was also observed in small veins and arteries on the level of terminal and respiratory bronchioles.

Pulmonary hypervolemia can lead to pressure elevation in the pulmonary circulation, a morphological reflection of which is hypertrophy of the muscular tunic of small arteries and enlargement of its cross section. For this reason, we made a morphometric study of arteries on the level of first- and second-order respiratory bronchioles (see Table). The table shows that, with 7-day AOH there was a tendency toward increase in diameter of the lumen and decline of Kernogen's index. With 7-day hypokinesia and 12-day AOH, the diameter of the lumen increased even more, while Kernogen's index decreased reliably, as compared to control ($P<0.05$). A decline of Kernogen's index without change in area of cross section of vascular muscular tunic is indicative of a functional change in tonus of small arteries of the muscular type [2, 10].

Morphometric characteristics of small arteries of the muscular type during AOH

Animal group	Measured parameters				
	outer diameter, μm	lumen diameter, μm	media thickness μm	media area, μm²	Kernogen index
Control	50±0,9	41±0,9	4,12±0,10	606±23	0,101±0,006
7-day AOH	51±0,7	43±0,8	3,90±0,10	570±20	0,084±0,005
7-day hypokinesia + 12-day AOH	52±0,8	45±0,9	3,64±0,12*	559±18	0,082±0,005**

* $P<0{,}02$
** $P<0{,}05$ (as compared to control)

A comparative study of monkey lungs during 7-day AOH and 7-day hypokinesia followed by 12-day AOH revealed that there was less marked venous and capillary plethora with 7-day hypokinesia.

Thus, the findings indicate that AOH elicits hypervolemia in the pulmonary circulation of monkeys, which is consistent with the results of investigation of hemodynamics of the human lung. Thus, it was established that, in humans, there is an increase in blood volume in the pulmonary circulation during short-term AOH [4, 8, 12], and the signs of plethora in the lungs progress with increase in duration of hypokinesia [3, 5, 14].

Development of venous and, particularly, capillary plethora in the absence of stasis in the lungs is a morphological confirmation of redistribution of blood in monkeys submitted to AOH and its deposition in the lungs. The latter leads to appreciable increase in weight of the lungs, particularly during 7-day hypokinesia and 12-day AOH. Morphometric findings--enlargement of lumen of small arteries and decline of Kernogen index--are also indicative of increasing plethora with increase in duration of the experiment.

We can include coarsening of the lung's elastic shell among the early signs of adaptive and compensatory changes. However, within the interval studied, there is still not enough time for sufficient development in the lungs of compensatory and adaptive mechanisms (in particular, hypertrophy of the walls of small arteries) aimed at establishing the required level of hemodynamics under new living conditions.

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UDC: 612.45+612.432+612.89].014.49.
014.477-064]-06:612.766.1

REGULATION OF PHYSICAL ACTIVITY IN ANTIORTHOSTATIC POSITION BY ACTING ON ADRENOSYMPATHETIC AND HYPOPHYSEO-ADRENOCORTICAL SYSTEMS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 13 Dec 83) pp 87-89

[Article by E. A. Shirinyan and O. M. Avakyan]

[Text] It is common knowledge that the adrenosympathetic and adrenocortico-pituitary systems play a leading role in adaptive reactions of an organism submitted to stress. There have been comprehensive investigations of their role and influence on different biological parameters during exposure to a physical load and a number of other stressors. The combined effect of physical and mental stimuli [4] and their influence on work capacity have been studied considerably less.

Our objective here was to test work capacity and endurance in antiorthostatic position under hypothermic conditions and their relation to baseline status of different elements of the adrenosympathetic and hypophyseo-adrenocortical systems.

Methods

Experiments were conducted on male albino rats weighing 130-150 g. A physical load in antiorthostatic position and with hypothermia was produced by means of a model that we developed [1, 3]. The animals were immobilized by the tail (head down) over water (t = 18°C), which only their forelegs and snouts touched. In such a position, the animals are forced to continuously make swimming movements. Thus, the animals physical activity was performed under conditions simulating some of the effects of weightlessness: a) increased blood in the head end of the body; b) absence of weight load on hind legs and, in part, forelegs.

Sympathectomy was performed by means of injections of 6-hydroxydopamine in a dosage of 35 mg/kg intraperitoneally (peripheral sympathectomy, or in a dosage of 350 μg into the cerebral ventricles (central sympathectomy). Saline was injected in control animals.

Bilateral adrenalectomy and adrenomedullectomy were performed on the dorsal side. Adrenalectomized animals were given, instead of water, a solution

containing 1% NaCl and 5% glucose. Hypophysectomy was performed by aspirating the gland through the auditory meatus. In some animals, the above-mentioned operations were performed without removal of the organ (pseudo-operated rats). Light ether anesthesia was used during the operations. The rats were submitted to stress on the 5th postoperative day and, in the case of central sympathectomy, on the 10th-12th day after the operation.

The animals were conditioned for physical activity 30 min per day for 7 weeks, with a 2-day interval each week.

Catecholamines (CA) and corticosterone (CS) were assayed fluorimetrically [2, 5].

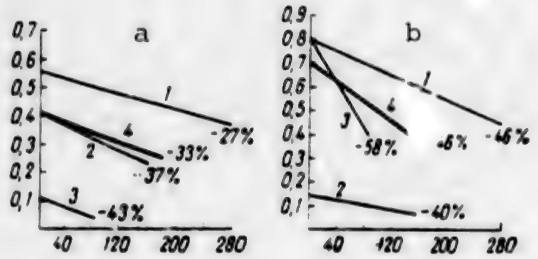
Changes in CA and CS content of organs and blood, as well as muscular endurance time in head-down position in tested groups of rats (% of corresponding control)

Animal group	Brain	Heart	Adrenals		Blood			Muscular endurance in head-down position, min
			CA	CS	E	NE	CS	
	NE	NE	μg/g		μg/ℓ			
Intact	0,42±0,02	0,69±0,03	967±38	30±1,2	5,3±1	11,1±2	18±1	181±13
Adrenalectomy	—	—			−98**	−55**	−92**	−50*
Adrenomedullectomy	—	—	−92**	—	−80**	−45*	—	—
Hypophysectomy	—	—	—	−80**	—	—	−85**	−56*
Peripheral sympathectomy	+20*	−90**	—	—	—	−37*	—	—
Central sympathect.	−88**	+19*	—	—	—	—	—	−47*
Conditioning	+20*	+25*	−30*	+30*	+25*	+23*	+30*	+55*

Note: By the day of the experiment, control (pseudo-operated) animals failed to demonstrate statistically significant changes in CA and CS, as compared to intact rats. The (+) or (-) signs signify increase or decrease, respectively, in percentile content. Only results, for which statistically reliable changes (one asterisk--$P<0.05$, two--$P<0.01$) were demonstrated are listed. Means of 7 experiments are given.

Results and Discussion

The results of the biochemical tests, which are listed in the Table, indicate that the procedures used made it possible to selectively control the activity of the systems under study. Thus, while there was drastic decline (by more than 90%) in concentration of both epinephrine (E) and CS in blood after adrenalectomy, we observed a decline of only CS after hypophysectomy and only CA after adrenomedullectomy. We failed to demonstrate reliable changes in norepinephrine (NE) content of the brain or cardiac tissue. Conversely, central or peripheral sympathectomy led to significant (over 85%) decrease in CA



Duration of endurance as a function of baseline NE content of the brain (a) and heart (b)

X-axis, endurance (min); y-axis, base levels of NE (µg/g); values for decline of NE levels (% of base values) is shown at time of muscular exhaustion

1) conditioning
2, 3) injection of 6-hydroxydopamine intraperitoneally and in the brain, respectively
4) control
+) animal death

concentration in the brain or heart. The endocrine element remained relatively intact. Conditioning the animals for physical activity led to a 20-30% increase in concentrations of CA and CS in all tested tissues.

The results of experiments with prolonged physical activity in head-down position are indicative of a close correlation between condition of different parts of the adrenosympathetic and pituitary-adrenocortical systems and resistance of the body when exposed to difficult conditions. Thus, the increase in tonus of all elements due to conditioning of animals to muscular activity led to 55% increase in maximum endurance. Peripheral sympathectomy and adrenomedullectomy had virtually no effect on constitutional resistance, whereas central sympathectomy, as well as hypophysectomy and adrenalectomy, elicited drastic decline of endurance.

The Table shows that in groups of animals with different disturbances in the adrenohypophyseal system endurance depended on base levels of CS in blood and adrenals, but not of CA.

As shown by the data illustrated in the Figure, the higher the base level of NE in the central nervous system and the lower its percentile decline under stress, the greater the animals' endurance. Such a correlation was not demonstrable in peripheral transmitter levels, i.e., duration of physical activity in antiorthostatic position was unrelated to NE content of the heart.

In works published in recent years, it was shown that there is reliable decline of maximum physical work capacity after hypophysectomy [10] and adrenalectomy or atrophy of the adrenal cortex [4]. However, work capacity does not diminish after removal of the adrenal medulla [8], although there is attenuation of the adrenocorticotropic response, leading to less elevation of blood CS level [9]. A decline of physical endurance was also demonstrated after central [6] and peripheral [7] sympathectomy.

The above data are also indicative of the substantial influence of the condition of the adrenosympathetic and adrenocortical-pituitary systems on tolerance to antiorthostatic stress, and they enable us to conclude that central adrenergic structures of the brain and adrenocorticotropic function of the pituitary that they control are the deciding factors of self-regulation in antiorthostatic position in the presence of multicomponent stress. When these elements are depressed, there is disruption of adaptive mechanisms that provide for physical work capacity under special conditions.

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UDC: 629.78:617.761-009.24-07-092.9

EFFECT OF EXPERIMENTAL MOTION SICKNESS ON POSTROTATORY NYSTAGMUS AND COUNTERROTATION ILLUSION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 20 Mar 84) pp 89-91

[Article by G. S. Ayzikov and O. N. Klyushnikova]

[Text] Man's exposure to frequent and prolonged vestibular stimuli, which are associated with development of motion sickness (MS), leads to change in reaction of the system of semicircular canals to angular accelerations. Flattening of the cupulogram has been found in seamen [8]. Prolonged operator work in a slowly revolving room lowers the intensity of the nystagmic reaction [5, 9, 10]. Analogous findings were made on animals, and the effects were more marked with prolonged rotation and hypergravity [5]. These facts are usually considered to be a reflection of adaptation processes in the vestibular system. A special role is attributed to prolonged and simultaneous stimulation of semicircular canals and otolith organs [4, 5]. Our objective here was to investigate the influence of MS produced by short-term but strong stimulation of the vestibular system on postrotatory nystagmus (PRN) and illusion of counterrotation (IC) during rotation tests (RT).

Methods

The studies were conducted on 9 male subjects 28-40 years of age who had no history of ear, nose and throat pathology or cerebrocranial trauma.

MS was induced by exposure to Coriolis and precession accelerations during performance of the test of I. I. Bryanov [2] by the subjects. The test was stopped upon appearance of grade II-III vestibulovegetative reactions (VVR) (marked perspiration, severe pallor of the integument, vertigo, nausea, retching) [7].

We used RT to study PRN and IC. The subjects were submitted to rotation on an electric revolving device following a trapezoid program with the head bent forward at an angle of 30°. They were rotated wearing lightproof glasses with the eyes closed, clockwise and counterclockwise with positive angular acceleration of $90°/s^2$ until a velocity of 30°/s was reached. Rotation at a constant velocity lasted 1.5 min. Then the chair was stopped in 0.3 s ("stop stimulus"). RT were conducted with clockwise and counterclockwise rotation at intervals of at least 3-5 min. During the RT, the subjects had to count backward mentally, successively subtracting 7 from a specified 3-digit number [6].

PRN was recorded by the electrooculographic method on an 8-channel Galileo (Italy) electroencephalograph with a time constant of 1 s. Analysis of the data included determination of duration of reaction, total number and mean frequency of beats, mean amplitude of rapid component (ARC) and PRN. The start and end of IC was recorded on the tape of an automatic recorder actuated by the subject's depression of a button.

Five series of studies of PRN and IC were conducted.

In the 1st series, we used RT 15 min after the test of I. I. Bryanov.

In the 2d series, the subjects took medication that provided relative protection against MS: mixture No 1 (cavinton 0.01 + scopolamine 0.0005), mixture No 2 (cavinton 0.01 + dedalon 0.05 + caffeine 0.1),* scopolamine 0.0005 and placebo. The agents were given using the double blind control method.

The subjects were tested (I. I. Bryanov test) 1 h after intake of medication and we used RT 15 min after this.

In the 3d series, we used RT after intake of medication. In the 4th series, we used RT without medication (baseline data).

In the 5th series, RT was used twice at an interval of 1.5 h.

To minimize habituation to vestibular stimuli, the tests were performed at least 1 week apart.

Results and Discussion

In all series, we failed to demonstrate statistically reliable differences in measured parameters of PRN during clockwise and counterclockwise rotation, i.e., no asymmetry of PRN was found.

In the 3d series, we observed a tendency toward decrease in total number of PRN beats, as compared to the base values, after intake of scopolamine, as well as mixture No 1. After intake of scopolamine there was also a tendency toward shorter duration of PRN.

In the 2d series, PRN underwent definite changes after the Bryanov test (see Table). There was significant decrease in total number of beats and duration of PRN. ARC and mean frequency of PRN showed virtually no change.

Analogous findings were made in the 2d series after intake of drugs (prevention of MS). We failed to demonstrate statistically significant differences between results in the 1st and 2d series.

In the 5th series, the measured PRN parameters were virtually identical after RT performed at a 1.5-h interval.

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*Mixtures Nos 1 and 2 had been studied as protective agents against MS by E. I. Matsnev and V. V. Usachev.

Counterrotation illusion: IC developed in backgrount RT. As a rule, they disappeared before termination of nystagmic reaction. No asymmetry of IC was demonstrable in any of the tests.

Intake of medication did not alter the nature, extent or duration of IC.

PRN changes in different series of studies

Series	ARC	Frequency of beats	Number of beats	Duration of nystagmus
1	2,33±0,33	1,53±0,23	22,82±3,37*	15,10±2,48*
2: Mixture No 1	2,87±0,49	1,58±0,2	19,67±5,2*	11,23±2,51*
Mixture No 2	3,02±0,35	1,72±0,38	25,72±5,6*	15,95±2,83*
Scopolamine	3,44±0,59	1,51±0,26	17,96±3,44*	10,82±1,9*
Placebo	3,22±0,4	1,85±0,25	24,56±3,13*	17,69±2,69*
3: Mixture No 1	2,94±0,25	1,55±0,14	37,61±5,87	24,71±3,13
Mixture No 2	3,01±0,23	1,78±0,16	46,75±6,07	24,76±2,04
Scopolamine	3,23±1,32	1,75±0,14	36,34±6,53	20,83±2,99
Placebo	3,49±0,4	1,67±0,18	43,06±7,53	25,26±3,37
4	3,01±0,33	1,77±0,17	47,63±9,81	26,09±3,52
5: 1-h RT	3,79±0,6	1,69±0,08	35,8±2,27	23,7±4,53
2-h RT	3,19±0,62	1,83±0,22	40,6±5,98	22,5±2,15

* $P<0{,}05$ as compared to baseline.

After the Bryanov test, with and without pharmacological agents, duration and severity of IC diminished.

When two RT were performed at an interval of 1.5 h, duration and severity of IC showed virtually no change.

A comparison of RT results after the test of I. I. Bryanov, with and without intake of preventive medication against MS, failed to reveal reliable differences in PRN parameters. These findings are probably indicative of absence of relationship between intensity of VVR and nystagmic reaction, since use of anti-MS agents, which diminished appreciably development of VVR, had virtually no effect on PRN characteristics. At the same time, vestibulosomatic reactions on the spinal level reflect well the extent of VVR in the form of change in motoneuron activity [1]. Apparently, oculomotor reflexes are rather autonomous and are not subject to influence by VVR. This could explain to a significant extent the absence of correlation between PRN characteristics and susceptibility to MS, as well as the fact that the prognostic value of PRN is minimal [1].

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UDC: 629.78:[574.685:595.772-139.3

CHEMICAL COMPOSITION OF MUSCA DOMESTICA L. LARVAL AND PUPAL BIOMASS WHEN DEVELOPING IN ORGANIC WASTE OF BIOLOGICAL LIFE-SUPPORT SYSTEM FOR MAN

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 18 Oct 83) pp 91-93

[Article by Ye. G. Golubeva, T. S. Gur'yeva and O. I. Tikhobayeva]

[Text] Heretofore, only man performed the function of the heterotrophic element in man-plants models [8]. In order to render such a system more closed, the model of its biocenotic structure should be considerably more complex. Studies aimed at finding organisms capable of occupying an ecological niche in a biological life-support system (BLSS) have been pursued for a long time [1, 5, 6] for the purpose of enhancing the energy efficiency and further close mass exchange. Among such organisms, as a representative of the detritus feed chain, Musca domestica L. housefly was suggested, as its larvae are efficient users of organic waste such as human and animal excreta [2, 3]. In developing the ecological system, the larval biomass recovered after utilization of waste can be used as feed for animals in the heterotrophic link. For this reason, it is rather important to assess the feed qualities of larval biomass.

Our objective here included investigation of chemical composition of biomass of prepupae and pupae of the housefly raised on BLSS waste.

Methods

Larvae developed in organic substrates consisting of BLSS waste and mixtures of different types of waste (Table 1). Newborn larvae were placed in substrates with 77-79% moisture (density of 4, 6, 8 and 10 larvae per gram substrate). We repeated the experiment 4 times with each variant of larval density at a temperature of 28°C and relative humidity of 55-60%, and we kept a record of average weight of the specimens. We assayed protein (total nitrogen by the method of Kjeldahl and Conway) and lipids (method of Soxhlet) in lyophilized samples of prepupal and pupal biomass. Reliability of differences between sample means was assessed by the Student criterion for small samples ($n = 7$) with level of significance $\alpha = 0.05$.

Results and Discussion

Average weight of prepupae and pupae of the housefly, when developed on all of the substrates, consistently declined with increase in larval density on the

substrate. The decrease in mass of prepupae and pupae with high larval density was associated with decrease in their protein content (Figures 1 and 2). While the reduction in prepupal mass with increase in population density to high levels was very distinct, the protein content diminished insignificantly. The identical nutritional value (according to protein) of prepupal biomass recovered after development at low and high larval density confirms once more a prior conclusion [2] to the effect that high larval density in the substrate is preferable for utilization of waste.

Table 1. Composition of tested substrates

Substrate No	Substrate components	Components, % of wet weight
1	Unadulterated human excreta	100
2	Japanese quail droppings	100
3	Unadulterated human excreta	90
	Japanese quail droppings	10
4	Unadulterated human excreta	80
	Japanese quail droppings	20
5	Unadulterated human excreta	60
	Japanese quail droppings	40
6	Unadulterated human excreta	80
	Mineralized wheat straw	20
7	Unadulterated human excreta	60
	Japanese quail droppings	30
	Mineralized wheat straw	10
8	Unadulterated human excreta	80
	Japanese quail droppings	10
	Mineralized wheat straw	10

The increase in fat content of prepupae and pupae with decrease in weight of the specimens can be evaluated merely as a tendency, since we failed to observe a clearcut correlation between these parameters on all substrates (Table 2). Pupae contained more protein than prepupae, but less fat than the latter (see Figure 2 and Table 2). Evidently, this is related to morphogenetic processes at the pupal stage, when a significant part of the substances in larval fatty tissue is broken down as a result of histolysis and transformed into protein compounds used to build imago tissues, mainly muscles of the adult insect.

There was no reliable difference in protein content of prepupae and pupae that developed on different substrates with the same larval density in them. Quail droppings were an exception; protein content of prepupae developing on them was higher and fat content, lower than on other substrates with the same larval density. Since protein content was virtually the same in prepupae and pupae developing on different BLSS waste, one should be governed primarily by several biometric parameters characterizing the condition of the population (total biomass at different stages of development, survival rate, mean weight of specimens, etc.) in assessing the quality of substrates for development of larvae.

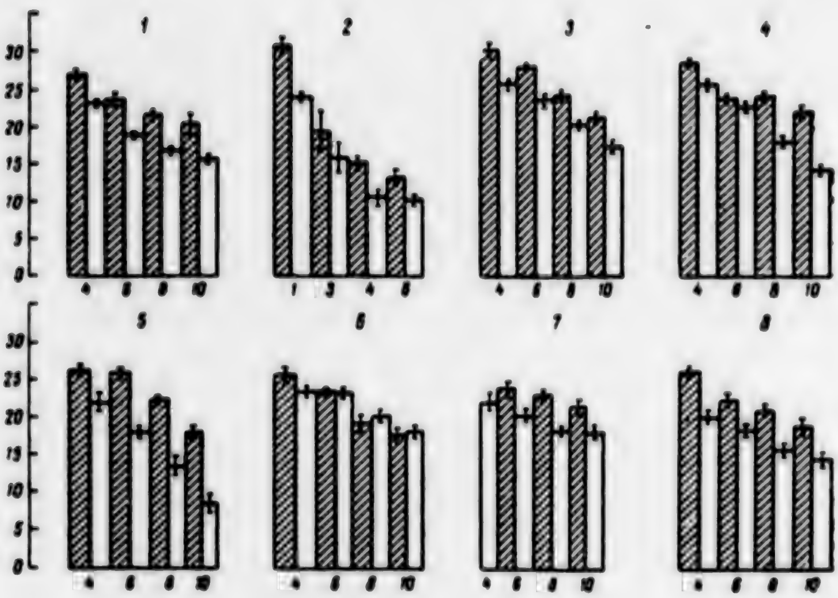

Figure 1. Mean weight of prepupae and pupae of housefly that developed in BLSS waste with different larval density in substrate.
Here and in Figure 2, Arabic numerals refer to substrates; white bars--pupae, striped--prepupae. X-axis, larval density in substrate (number of larvae per gram substrate); y-axis, mass (mg)

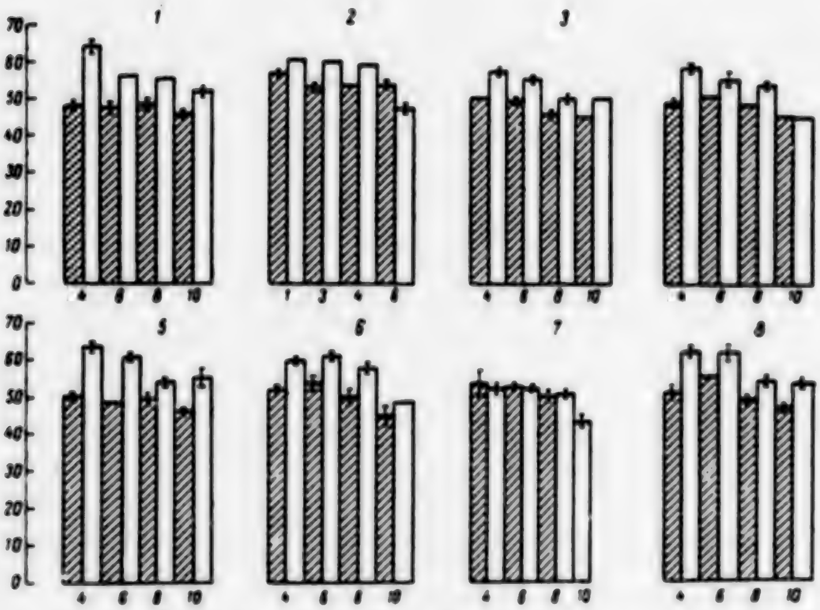

Figure 2. Protein content in housefly prepupae and pupae developing on BLSS waste with different larval density in substrate.
Y-axis, protein (%)

Table 2. Fat content in Musca domestica L. pupae and prepupae developing in BLSS organic waste with different larval density in substrate

Substrate No	Prepupa				Pupa			
	larvae per gram substrate							
	4	6	8	10	4	6	8	10
1	26.3 ± 0.6	30.5 ± 0.5	30.9 ± 0.5	31.2 ± 0.2	19.8 ± 0.4	20.3 ± 0.5	22.2 ± 0.2	21.3 ± 0.3
2	13.0 ± 0.1	11.5 ± 0.5	11.0 ± 0.3	10.5 ± 0.5	—	—	—	—
3	27.4 ± 0.2	30.1 ± 0.1	31.9 ± 0.3	31.4	20.5 ± 0.3	24.5 ± 0.3	24.0	25.0 ± 0.2
4	28.1 ± 0.1	30.9 ± 0.3	32.3 ± 0.3	34.3 ± 0.1	26.2	—	22.0	22.5 ± 0.3
5	27.3 ± 0.1	28.6 ± 0.2	28.4 ± 0.2	—	20.0 ± 0.2	20.3 ± 0.2	21.4 ± 0.3	—
6	26.7 ± 0.[illegible]	29.2 ± 0.2	24.0	29.0	19.9 ± 0.5	21.5 ± 0.3	21.5 ± 0.5	21.7 ± 0.4

Housefly larvae and pupae that developed on BLSS waste contained significant amounts of protein and fat--50-53 and 27-30%, respectively (average for all densities of larvae placed in substrates; see Figure 2 and Table 2). Protein content was about the same (50%) in prepupae raised in swine manure [7]. Protein content of prepupal biomass was higher--60%--when they developed in household waste (garbage) [11]. As for pupae that developed on BLSS waste, they did not differ in protein content from those that developed on chicken droppings (60-63% protein) [9, 10]. However, it should be noted that fat content of prepupae and pupae that developed on BLSS waste was 1.5-2 times higher than in those developed on swine manure, fowl droppings and garbage.

The results of our studies indicate that the chemistry of housefly prepupal and pupal biomass does not depend appreciably on properties of the nutrient substrate. According to data of Soviet and American researchers, housefly larvae that utilized fowl droppings and swine manure, constituted a proper diet for feeding various farm animals [4, 9-11]. In view of the fact that the chemical composition of larvae does not depend much on the properties of the nutrient substrate, it can be assumed that the biomass of larvae recovered with utilization of BLSS organic waste will be a proper feed for animals in the heterotrophic link of the system.

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UDC: 629.78:]574.685:635.67

EFFECT OF SUBSTRATE MOISTURE ON GROWTH AND STRUCTURE OF CORN LEAF

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 19, No 2, Mar-Apr 85 (manuscript received 21 Jun 83) pp 94-96

[Article by A. F. Safonkin]

[Text] Experiments with higher plants aboard space vehicles are conducted in instruments with artificial substrates. Normal plant growth under such conditions depends on many environmental parameters. Water is one of the principal parameters that determines many vital functions.

The absence of positive results from a number of experiments with higher plants in space stations can be attributed to other than optimum watering of plants, rather than negative biological effects of weightlessness. In some cases there was excess watering and in others, insufficient supply of substrate water in the root region. For this reason, it is quite important to investigate the structures of plants that react to substrate moisture, define the range of moisture required to conduct experiments with higher plants aboard space stations. Growth and development of plants are determined not only by presence of moisture, but amount of oxygen in the substrate. At low moisture levels in the substrate, plant growth is limited by the water shortage and at high moisture levels, by the shortage of oxygen. As a rule the influence of these factors was investigated in cases of maximum flooding or drought [3, 4]. Several works reflect attempts to study the effect of intermediate substrate moisture on plants [1, 2, 5].

The leaf system and stomata play an important part in maintaining a normal water balance [6-8]. When there is insufficient water in the substrate, there is reduction of plant leaf surface, increase in number of stomata and epidermal cells per unit leaf surface and some decrease in their size.

Excessive water at sowing time leads to insufficient delivery of oxygen to seeds, as a result of which there is delayed sprouting and subsequent growth of plants [4]. In the case of anaerobiosis, one observes intensified release by roots of mineral salts and organic compounds, including ethanol. This alcohol remains in the root zone and has an adverse effect on plant growth [4].

Our objective here was to track the changes in growth and structure of corn leaves as related to substrate moisture content.

Methods

Corn was grown by the method of substrate hydroponics in vegetation containers. A porous hydrophil membrane *1* (Figure 1) was tightly secured at about 5 mm from the bottom of the vegetation container. The space between the bottom and membrane *2* was filled with water and connected through tube *3* with water container *4*. Pearlite with salts *5* was sprinkled in a 4-cm layer on the membrane. With such construction of the vegetation container, moisture of pearlite depends on water level in the bottom compartment *4*. Total moisture capacity of the substrate was 6.5 mℓ water per gram pearlite. The graph illustrates pearlite moisture as a function of height of the water column H (Figure 2).

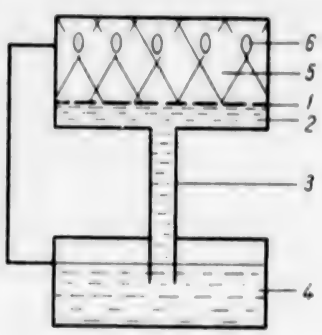

Figure 1.
Diagram of vegetation container for experiments with substrates differing in moisture content
1) porous hydrophil membrane
2) space between bottom of container and membrane
3) tube filled with water
4) container with water
5) salt-saturated pearlite
6) corn seeds
H) height of water column

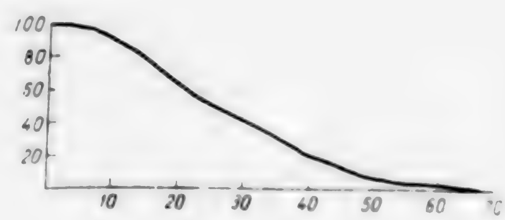

Figure 2.
Water saturation of substrate as a function of height of column of water
X-axis, height of water column (cm);
y-axis, pearlite moisture content (%)

A total of 21 corn seeds *6* (see Figure 1) was planted on an area of 500 cm^2 reserved for each experimental variant. The seeds were in the substrate at a depth of 1 cm. We tested substrates with moisture content of 10, 20, 30, 40, 55, 70, 85, 95 and 100% of total water capacity. The experiments were conducted under conditions of 24-h/day illumination, air temperature of 22°C and relative humidity of 55%. They lasted 18 days from the time the seeds were sown.

The above-ground parts of the plants in each experimental variant were weighed, leaf length was measured and then they were dried. Part of the leaves were fixed according to Brodskiy. Before making total preparations, the leaves were stained with Schiff's reagent. On the preparations, we determined the number and size of stomata and epidermal cells in the top and bottom surfaces of the leaf. Stomata and epidermal cells were measured using an ocular micrometer at 420× magnification.

Results and Discussion

Figure 3a illustrates emergence of seeds as a function of substrate moisture. As can be seen, the seeds do not sprout at 10% moisture, In the range of 20 to 85%, moisture content had no effect on emergence, which ranged from 80 to 100%. Moisture in excess of 95% inhibited germination of corn seeds. with 100% moisture in the substrate, the seeds did not sprout at all.

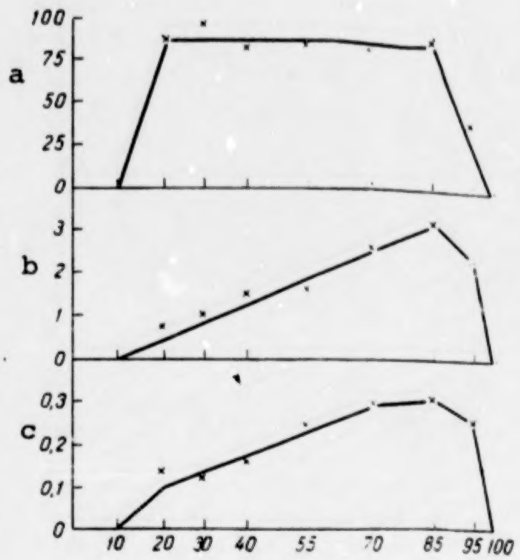

Figure 3.
Effect of substrate moisture content on seed emergence, wet and dry weight of maize plants
X-axis, pearlite moisture, %
a) emergence of corn seeds (%)
b,c) wet and dry weight (g), respectively, of corn plants scaled to 1 plant

Plant biomass increment depends on moisture of substrate. Maximum weight of corn seedlings is observed with substrate moisture content of 85% of moisture capacity (Figure 3b and 3c).

Changes in number and size of stomata and epidermal cells of maize plants as a function of substrate moisture content are listed in Tables 1 and 2. The results of measurements revealed that the number of stomata per unit leaf surface depends on substrate moisture. The largest number of stomata are on the bottom leaf surface with 30% substrate moisture, and it constitutes $106\pm6/mm^2$. With increase in moisture to 95% there is decrease in number of stomata to $76\pm4/mm^2$. There are fewer stomata per unit leaf area o the top surface of the leaf than on the bottom one, but the pattern of increase in number of stomata with decrease in moisture is even more distinct. Thus, with 20% moisture they constitute $74\pm8/mm^2$, and with 95% only 40±5. There was the lowest number of stomata per unit leaf area with substrate moisture content of 85% (33±3; see Table 1).

Table 1. Effect of substrate moisture on number of stomata/mm^2 corn leaf and their dimensions

Substr. moist., %	Top surface of leaf			Bottom surface of leaf		
	number of stomat.	length	width	number of stomata	length	width
20	74±8	0,036±0,003	0,024±0,002	95±5	0,044±0.005	0,029±0.005
30	66±4	0,032±0,002	0,021±0,003	106±6	0,035±0.003	0,019±0.003
40	61±7	0,033±0,003	0,021±0,003	86±9	0,033±0.003	0,018±0.002
55	47±7	0,035±0,006	0,020±0,003	101±10	0,037±0.005	0,021±0,004
70	42±5	0,036±0,002	0,021±0,001	92±3	0,035±0.004	0,024±0.004
85	33±3	0,050±0,009	0,032±0,004	63±6	0,050±0.006	0,030±0.005
95	40±5	0,037±0,004	0,026±0,005	76±4	0,038±0.003	0,026±0,004

Table 2. Effect of substrate moisture on dimensions of corn leaf cells (in mm)

Substrate moisture, %	Top surface of leaf				Bottom surface of leaf			
	square cells		rectang.cells		square cells		rectang. cells	
	length	width	length	width	length	width	length	width
20	0,071±0,008	0,028±0,007	0,107±0,017	0,023±0,003	0,099±0,035	0,037±0,016	0,124±0,031	0,021±0,004
30	0,069±0,007	0,021±0,003	0,105±0,039	0,019±0,003	0,075±0,010	0,027±0,001	0,114±0,032	0,022±0,003
40	0,083±0,014	0,032±0,003	0,129±0,029	0,026±0,003	0,069±0,006	0,024±0,004	0,099±0,027	0,023±0,004
55	0,063±0,014	0,022±0,006	0,139±0,041	0,022±0,004	0,075±0,016	0,028±0,005	0,115±0,020	0,022±0,005
70	0,072±0,017	0,039±0,005	0,105±0,034	0,024±0,005			0,139±0,00	0,019±0,00
85	0,086±0,027	0,049±0,008	0,135±0,035	0,036±0,006	0,074±0,035	0,032±0,00[illegible]	0,146±0,011	0,026±0,005
95	0,075±0,00	0,029±0,002	0,113±0,021	0,023±0,003	0,076±0,011	0,025±0,003	0,136±0,030	0,024±0,003

The dimensions and shape of corn leaf stomata also vary, depending on substrate moisture. At low levels of moisture (20%) the stomata have a length of 0.036±0.003 mm on the top surface of the leaf and 0.44±0.005 mm on the bottom; with 85% moisture, the figures are 0.050±0.009 and 0.050±0.006 mm, respectively (see Table 1). At 20% moisture, stoma width is 0.024±0.002 mm on the top surface and 0.24±0.005 mm on the bottom; with 85% moisture, width is 0.032±0.004 and 0.030±0.005 mm, respectively. With optimum substrate moisture, the stoma becomes larger and the length of the stomatal fissure increases. As a result, this fissure opens on a large area, increasing transpiration from intercellular spaces.

The epidermal cells of the corn leaf were arbitrarily divided into two types: "rectangular" and "square." Cells whose length was more than 3 times greater than their width were classified as rectangular. The length and width of cells of both types are listed in Table 2. The dimensions of epidermal cells are not very susceptible to the influence of substrate moisture. The coefficient of correlation between substrate moisture and width of epidermal cells on the top surface of the leaf is 0.046, and between moisture and length it is 0.068. This pattern is even less marked on the bottom surface of the leaf.

Thus, substrate moisture content has the strongest effect on dimensions and number of stomata per unit area of the top corn leaf surface. This indicates that the stomata of the top leaf surface play an important part in water balance of plants.

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